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Gaithersburg, MD 20899

Baseline Measures for Improving Housing Durability

Robert E. Chapman and Christine A. Izzo

PATH
PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

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Robert E. Chapman and Christine A. Izzo

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Building and Fire Research Laboratory

and

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U.S. DEPARTMENT OF COMMERCE
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Abstract

The Partnership for Advancing Technology in Housing (PATH), a program of the U.S. Department of Housing and Urban Development, is a public/private partnership in which leaders of the home building, product manufacturing, and insurance and financial industries join forces with representatives of federal agencies concerned with housing. PATH is concerned with the following three goals: (1) developing new housing technologies; (2) disseminating information about new and existing housing technologies; and (3) studying and establishing mechanisms for sustained housing technology development. The objectives of PATH are to improve the quality, affordability, durability, and energy efficiency of today's new and existing homes; to strengthen the technology infrastructure of the United States; and to help create the next generation of American housing. To accomplish these objectives, PATH has established a vision for improving housing affordability, energy efficiency and environmental protection, durability, and disaster resistance and safety. It is essential to have baseline data for the PATH vision to determine the success of actions taken to improve the competitiveness of the residential sector of the U.S. construction industry. This report provides a detailed set of baseline measures for improving housing durability. Specifically, it examines the key sources of construction industry data and extracts from them a single, consistent set of baseline measures that can be used to monitor progress towards improving housing durability.

Keywords

building economics; construction; costs; durability; economic analysis; housing; maintenance and repair; residential improvements; service life

Preface

This study was conducted by the Office of Applied Economics in the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST). The study was sponsored by the Partnership for Advancing Technology in Housing (PATH) program at the U.S. Department of Housing and Urban Development (HUD). The BFRL project, of which this study is a part, seeks to develop service life prediction tools, evaluation methods, decision support software, and other innovative tools and technologies to help PATH achieve its vision of improving durability and reducing maintenance costs by 50 % by 2010. The intended audience for this document is the public and private sector members of PATH, construction industry representatives, and other interested parties.

Use of Non-SI Units in a NIST Publication

The policy of NIST is to use the International System of Units (metric units) in all of its publications. However, in North America in the construction and building materials industry, certain non-SI units are so widely used instead of SI units that it is more practical and less confusing to include measurement values for both customary units and metric units. Throughout this document, measurement values stated in customary units are listed first followed by the corresponding values in metric units within parentheses.

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The authors wish to thank all those who contributed so many excellent ideas and suggestions, which they have attempted to incorporate into this report. The authors wish to thank Mr. David Engel, Ms. Andrea Vrankar, Dr. Carlos Martin, and Mr. William Freeborne of the Office of Policy Development and Research at the U.S. Department of Housing and Urban Development (HUD) for their guidance, suggestions, and support. HUD's Office of Policy Development and Research, in collaboration with the private sector, provides leadership and administrative support to the Partnership for Advancing Technology in Housing (PATH) program. Thanks are also due to Dr. Christopher C. White of the Building Materials Division at NIST's Building and Fire Research Laboratory (BFRL) for his efforts to coordinate the PATH Durability program within BFRL. Special appreciation is extended to Drs. Harold E. Marshall and Sieglinde K. Fuller of BFRL's Office of Applied Economics for the thoroughness of their reviews and for their many insights and to Mrs. J'aime Maynard for her assistance in preparing the manuscript for review and publication. Thanks are due to Dr. Stephen F. Weber of the Office of Applied Economics for his assistance in formulating this research effort. The report has also benefited from the review and technical comments provided by Mr. Stephen A. Cauffman of BFRL's Structures Division.

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List of Acronyms

Acronym	Definition
AHS	American Housing Survey
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BFRL	Building and Fire Research Laboratory
DOE	Department of Energy
HUD	Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air-Conditioning
LPG	Liquefied Petroleum Gas
NAHB	National Association of Home Builders
NFO	National Family Opinion
NIST	National Institute of Standards and Technology
PATH	Partnership for Advancing Technology in Housing
R&D	Research and Development
RECS	Residential Energy Consumption Survey

Executive Summary

The Partnership for Advancing Technology in Housing (PATH), a program of the U.S. Department of Housing and Urban Development, is a public/private partnership in which leaders of the home building, product manufacturing, and insurance and financial industries join forces with representatives of federal agencies concerned with housing. PATH is concerned with the following three goals: (1) developing new housing technologies; (2) disseminating information about new and existing housing technologies; and (3) studying and establishing mechanisms for sustained housing technology development. The objectives of PATH are to improve the quality, affordability, durability, and energy efficiency of today's new and existing homes; to strengthen the technology infrastructure of the United States; and to help create the next generation of American housing. To accomplish these objectives, PATH has established a vision for improving housing affordability, energy efficiency and environmental protection, durability, and disaster resistance and safety. It is essential to have baseline data for the PATH vision to determine the success of actions taken to improve the competitiveness of the residential sector of the U.S. construction industry.

This report provides a detailed set of baseline measures for improving housing durability. The averages of current practice—defined in this report as industry performance in 1997—are used to develop the baseline measures for improving housing durability. This report examines the key sources of construction industry data and extracts from them a single, consistent set of baseline measures that can be used to monitor progress towards improving housing durability. Specifically, the report describes the key construction industry data sources and their associated data elements, demonstrates how each data source provides perspective on one or more dimensions of the construction industry, and synthesizes key data elements into a common format for specifying the baseline measures for improving housing durability.

This document has six chapters. Chapter 1 explains the purpose, scope, and general approach. Chapter 2 introduces the PATH vision and describes how a well-defined set of metrics is used to develop the baseline measures. Chapter 3 provides an overview of construction industry data. The overview provides the context within which the baseline measures for improving housing durability are developed. Chapter 4 presents the baseline measures of service life for selected building elements. Chapter 5 presents the baseline measures of durability-related costs. Specific cost categories covered include major replacements, maintenance and repair, and alterations. Information on energy expenditures is also presented. Chapter 6 concludes the document with a summary and suggestions for further research.

Chapter 2 provides perspective on the PATH vision. First, each component of the PATH vision is introduced and described. Next, the process for developing the baseline measures for improving housing durability is described. This process involves: (1) specifying data relationships; (2) collecting and compiling the key data and supporting information for the base year, 1997; (3) defining metrics; and (4) producing the metrics in

a tabular summary form and, where appropriate, producing charts and graphs to depict the metrics. Criteria are then presented which ensure that the data selected for analysis are well defined, consistent, and replicable. The chapter also outlines a strategy for using the baseline measures to drive performance improvement.

Chapter 3 provides a data-oriented snapshot of the U.S. construction industry. It provides the context within which the baseline measures for improving housing durability are developed.

Information is first presented on the value of construction put in place to show the size of the construction industry and each of its four sectors. The four sectors, which taken together define the construction industry, are residential, commercial/institutional, industrial, and public works. Data from 1994 through 2000 are used to highlight the magnitude of construction-related investments in each sector. Data from 1997 are then used to establish the relative shares of construction-related investments for each sector. These data demonstrate that the residential sector accounts for approximately 45 % of the total value of all construction put in place.

Section 3.2 uses information on the residential sector both to focus on its importance within the overall construction industry and to define its key components. Information on investment activity is used to highlight the key components of residential construction. The nature of construction activity is then presented to differentiate expenditures that are investment-related (e.g., new construction, additions and alterations, and major replacements) versus those that are associated with day-to-day operations (e.g., maintenance and repair and energy).

Section 3.3 places special emphasis on identifying and detailing the key characteristics of housing. Information on the number of housing units by type of housing unit is used to classify units into key categories, some of which are used throughout the report (e.g., single-family detached). Information on durability-related expenditures is then presented. A series of tables is used to illustrate how expenditures vary across property types (i.e., owner-occupied or rental) and type of job (e.g., roof replacements). Next, a brief analysis of household expenditures for energy is presented. Expenditures by property type, fuel type (e.g., electricity), and end use (e.g., space heating) are used to highlight different aspects of household expenditures for energy. Section 3.3 concludes with a summary table in which selected cost data are presented.

Chapter 4 traces the development of the baseline measures of service life. The service life of a building component or material is defined as the period of time—measured in years—after installation during which all properties meet or exceed the minimum acceptable values when routinely maintained. Three data sources are described and matched to the key types of building elements (e.g., roofs, siding, and furnaces). The three data sources are: (1) American Society for Testing and Materials (ASTM) Standard Guide E 2136; (2) an article from Housing Economics published by the National Association of Home Builders (NAHB); and (3) the 1997 edition of the Whitestone

Building Maintenance and Repair Cost Reference. The baseline measures of service life are then derived from the source data.

Table ES-1 summarizes the various baseline measures of service life presented in Chapter 4. The table is organized to serve as a quick reference; it includes a brief description of each measure, the value of the measure, and the source of the service life data.

Table ES-1. Summary of Baseline Measures of Service Life

Building Element	Service Life in Years	Source
Plumbing		
Fixtures	15 - 25	ASTM E 2136
Enamel steel sinks	5 - 10	Housing Economics
Enamel cast iron sinks	25 - 30	Housing Economics
China sinks	25 - 30	Housing Economics
Stainless steel sinks	40	Whitestone
Low quality faucets	13 - 15	Housing Economics
High quality faucets	15 - 20	Housing Economics
Hot water heater	5 - 15	ASTM E 2136
Gas water heater	11 - 13	Housing Economics
Electric water heater	14	Housing Economics
Hot water storage tank	50	Whitestone
HVAC		
Evaporative coolers	8 - 15	ASTM E 2136
Central air conditioning unit	15	Housing Economics
Window air conditioning unit	10	Housing Economics
Air conditioner, indoor DX packaged, air cooled	20	Whitestone
Furnaces	15 - 20	ASTM E 2136
Gas or oil fired furnaces	18	Housing Economics
Gas house furnaces	15	Whitestone
Heat pumps	15	Housing Economics
Siding		
Wall finish - easily renewable	4 - 10	ASTM E 2136
Wall finish - difficult to renew	20 - 60	ASTM E 2136
Siding - wood	10 - 100	Housing Economics
Siding - metal (steel)	50 - Lifetime	Housing Economics
Siding - aluminum	20 - 50	Housing Economics
Siding - vinyl	50	Housing Economics
Aluminum siding, 1st floor	80	Whitestone

Table ES-1. Summary of Baseline Measures of Service Life (continued)

Building Element	Service Life in Years	Source
Roofing		
Roof covering	12 - 25	ASTM E 2136
Roof covering - asphalt and wood shingles and shakes	15 - 30	Housing Economics
Roof covering - tile	50	Housing Economics
Roof covering - slate	50 - 100	Housing Economics
Roof covering - sheet metal	20 - 50+	Housing Economics
Replace new over existing asphalt shingle roof	20	Whitestone
Removal and replacement of asphalt shingle roof	40	Whitestone
Windows		
Windows	20 - 25	ASTM E 2136
Windows - wood casement	20 - 50	Housing Economics
Windows - aluminum casement	10 - 20	Housing Economics
Doors		
Doors	20 - 25	ASTM E 2136
Exterior doors (protected overhang)	80 - 100	Housing Economics
Exterior doors (unprotected and exposed)	25 - 30	Housing Economics
Solid core (painted) exterior doors	40	Whitestone

Chapter 5 traces the development of baseline measures of durability-related costs. Two data sources are described and matched to the key types of durability-related costs (e.g., replacements of roofs and siding, maintenance and repair expenditures, and expenditures for energy). The two data sources are the American Housing Survey (AHS) and the Residential Energy Consumption Survey (RECS). Both the AHS and RECS data sources are available in electronic format as "public-access" files. The baseline measures of durability-related costs are then derived from the source data.

Table ES-2 provides a summary of the various baseline measures of durability-related costs. The table is organized to serve as a quick reference; it consists of two parts. Part A reports costs by building element on a per household basis. Building elements are grouped under three cost categories—major replacements, maintenance and repair, and alterations. The remaining column headings under Part A of Table ES-2 are a descriptive heading and dollar values associated with a series of statistical measures. The descriptive heading designates the type of unit (i.e., all units (A) or single-family detached units (S)) and who did the work (i.e., contractor (C) or household (H)). The statistical measures are recorded in one of four subheadings under the "Cost per Household" heading. The four subheadings correspond to the following statistical measures: the 25th percentile, the median (50th percentile), the 75th percentile, and the mean.

Table ES-2. Summary of Baseline Measures of Durability-Related Costs

Part A: By Cost Element per Household

Building Element	Designation	Cost per Household			
		25th Percentile	Median	75th Percentile	Mean
Major Replacements					
Roof	AC	1 800	2 700	4 500	3 667
Roof	SC	1 800	2 800	4 500	3 743
Roof	AH	700	1 300	2 500	1 829
Roof	SH	800	1 400	2 500	1 873
Doors or windows	AC	300	951	2 550	2 012
Doors or windows	SC	350	1 000	2 900	2 108
Doors or windows	AH	120	250	600	590
Doors or windows	SH	120	300	600	628
All siding	AC	3 000	5 419	8 900	6 433
All siding	AH	1 000	2 000	3 000	2 935
Furnace, heat pump, or boiler and maintenance and repair of furnace/heating equipment parts	AC	1 000	1 800	2 700	2 058
Central air conditioning	AC	1 500	2 400	3 500	2 624
Maintenance and Repair					
Finished flooring	AC	400	1 000	2 000	1 626
Finished flooring	AH	100	250	600	643
Interior water pipes	AC	80	220	500	640
Interior water pipes	AH	20	50	100	113
Siding	AC	400	1 200	2 300	1 832
Alterations					
Kitchen cabinets	AC	2 000	4 000	8 000	5 914
Kitchen cabinets	AH	500	1 500	4 000	2 399
Kitchen flooring	AC	500	1 000	2 000	1 467
Kitchen counter tops	AC	250	700	1 200	1 046
Bathroom cabinets	AC	500	2 000	5 000	3 440
Bathroom cabinets	AH	200	500	1 000	1 056
Bathroom flooring	AC	250	500	1 500	1 283
Bathroom counter tops	AC	100	300	1 000	920
Bathroom tub/shower	AC	250	520	1 500	1 142

Table ES-2. Summary of Baseline Measures of Durability-Related Costs (continued)

Part B: Key Energy Expenditures per Unit of Floor Area

Type of Expenditure	Energy Expenditure	
	$/ft^2	$/m^2
Total	0.93	10.04
End Use		
Space heating	0.29	3.12
Air-conditioning	0.10	1.03
Water heating	0.14	1.46
Refrigerators	0.08	0.90
Other appliances and lighting	0.36	3.84
All end uses	0.93	10.04
Types of Fuel		
Electricity	0.61	6.59
Natural gas	0.39	4.23
Fuel oil	0.50	5.39
Kerosene	0.10	1.12
LPG	0.34	3.62
All fuels	0.93	10.04

Part B reports energy expenditures per unit of floor area. Energy expenditures per unit of floor area are estimates because the RECS does not collect data on the actual floor area of the housing units surveyed. The RECS does ask respondents to indicate which of seven size categories their housing unit falls into. Since the AHS public-access files contain values for each surveyed housing unit's floor area, they were used to "estimate" the median size for each RECS size category. The median values for each size category were used to estimate energy expenditures per unit of floor area. Energy expenditures in both $/ft^2 and $/m^2 are reported in Part B. Both aggregated (e.g., all fuels) and disaggregated (e.g., electricity) values are reported.

Chapter 6 discusses additional areas of research that might be of value to government agencies and private sector organizations that are concerned about improving durability and reducing maintenance costs. These areas of research are concerned with: (1) the dissemination of detailed information on service life data and durability-related costs for selected building elements; (2) the use of life-cycle cost analysis as a means of combining service life data and durability-related costs into a coherent format for choosing among alternative building materials, components, and systems; (3) the treatment of interdependencies between building components and systems; and (4) the measurement and evaluation of progress toward achievement of the PATH vision.

1. Introduction

1.1 Background

The competitiveness of the residential sector of the construction industry is a key contributing factor to the growth of the Nation's economy. The U.S. Department of Housing and Urban Development (HUD) has actively sought to promote competitiveness within the residential sector through focused research, demonstration projects, and public-private partnerships. Two public-private partnerships in which HUD has played an especially active role are the Subcommittee on Construction and Building of the National Science and Technology Council and the Partnership for Advancing Technology in Housing (PATH).

The National Science and Technology Council, a cabinet-level group chaired by the president, is charged with setting federal technology policy and coordinating R&D strategies across a broad cross-section of public and private interests. It has established nine research and development committees, including the Committee on Technology, to collaborate with the private sector in developing a comprehensive national technology policy. The purpose of the Committee on Technology is to enhance the international competitiveness of U.S. industry through federal technology policies and programs. The Subcommittee on Construction and Building of the Committee on Technology coordinates and defines priorities for federal research, development, and deployment related to the industries that produce, operate, and maintain constructed facilities, including buildings and infrastructure.[1]

The mission of the Subcommittee on Construction and Building—in cooperation with U.S. industry, labor, and academia—is to enhance the competitiveness of U.S. industry and promote public safety and environmental quality through research and development, and to improve the life-cycle performance of constructed facilities. To accomplish its mission, the Subcommittee on Construction and Building has established seven National Construction Goals in collaboration with a broad cross section of the construction industry.[2] The goals are focused on the four major sectors of the construction industry—residential, commercial/institutional, industrial, and public works. To make the goals operative, data describing current practices of the U.S. construction industry are needed to establish baselines against which industry can measure its progress towards achieving the seven National Construction Goals.[3]

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[1] Wright, Richard N. 1995. "Government and Industry Working Together." *Construction Business Review* (January/February): pp. 44-49.

[2] Wright, Richard N., Arthur H. Rosenfeld, and Andrew J. Fowell. 1995. *Construction and Building: Federal Research and Development in Support of the U.S. Construction Industry*. Washington, DC: National Science and Technology Council.

[3] The seven National Construction Goals are concerned with: (1) reductions in the delivery time of constructed facilities; (2) reductions in operations, maintenance, and energy costs; (3) increases in occupant productivity and comfort; (4) reductions in occupant-related illnesses and injuries; (5) reductions in waste and pollution; (6) increases in the durability and flexibility of constructed facilities; and (7) reductions in construction worker illnesses and injuries.

HUD's active participation in the Subcommittee on Construction and Building, from its inception in 1994, led to a sharpened focus on the needs of the residential sector. Between 1994 and 1997, HUD worked with the residential sector of the construction industry—represented by home builders, code officials, product manufacturers, and other interested parties—to develop a research plan for implementing the National Construction Goals in the residential sector. Discussions within the Subcommittee on Construction and Building and close collaboration with the private sector led to the creation of PATH under HUD's leadership. Early on, HUD recognized the value of using goals as a performance improvement tool and for marshaling support for PATH. The PATH goals were first promulgated in 1997; PATH was officially launched on May 4, 1998.

PATH is concerned with the following three goals: (1) developing new housing technologies; (2) disseminating information about new and existing housing technologies; and (3) studying and establishing mechanisms for sustained housing technology development. The objectives of PATH are to improve the quality, affordability, durability, and energy efficiency of today's new and existing homes; to strengthen the technology infrastructure of the United States; and to help create the next generation of American housing. To accomplish these objectives, PATH has established a vision for improving housing affordability, energy efficiency and environmental protection, durability, and disaster resistance and safety.

It is essential to have baseline data for the PATH vision to determine the success of actions taken to improve the competitiveness of the residential sector of the U.S. construction industry. In addition, baseline measures will make it possible to demonstrate the benefits of advanced technologies and practices and to guide decision makers in prioritizing potential programs.

Consequently, PATH is developing baseline measures that characterize current industry performance with respect to the PATH vision.[4, 5] The averages of current practice—defined in this document as industry performance in 1997—will become the baseline measures for improving housing durability.

1.2 Purpose

The purpose of this document is to provide a detailed set of baseline measures for improving housing durability. As such, it describes data sources, data classifications, and the metrics used to develop the baseline measures. Extensive use of charts and tables is made throughout this document to illustrate the process by which the baseline measures were developed.

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[4] U.S. Department of Housing and Urban Development. 2000. *Partnership for Advancing Technology in Housing (PATH): Strategy and Operating Plan.* Washington, DC: Office of Policy Development and Research.

[5] National Association of Home Builders Research Center. 1998. *Baseline Data and Information Resource Guide.* Upper Marlboro, MD: National Association of Home Builders Research Center, Inc.

The intended audience for this document is the public[6] and private[7] sector members of PATH, construction industry representatives, and other interested parties. In addition, because this document includes both detailed information on the baseline measures for improving housing durability and a compilation of statistics on the four sectors and the construction industry as a whole, it is anticipated that this document will serve as a resource reference for readers with a wide variety of interests in the construction industry.

1.3 Scope and Approach

This report examines the key sources of construction industry data and extracts from them a single, consistent set of baseline measures that can be used to monitor progress towards achieving the PATH vision of improving housing durability and reducing maintenance costs by 50 % by 2010. Specifically, the report describes the key construction industry data sources and their associated data elements, demonstrates how each data source provides perspective on one or more dimensions of the construction industry, and synthesizes key data elements into a common format for specifying the baseline measures for improving housing durability.

This document has five chapters in addition to the Introduction. Chapter 2 introduces the PATH vision and describes how a well-defined set of metrics is used to develop the baseline measures. Chapter 3 provides an overview of construction industry data. The overview provides the context within which the baseline measures for improving housing durability are developed. Chapter 4 presents the baseline measures of service life for selected building elements. Key baseline measures of service life are summarized in Table 4-4, which appears at the end of Chapter 4. Chapter 5 presents the baseline measures of durability-related costs. Specific cost categories covered include major replacements, maintenance and repair, and alterations. Information on energy expenditures is also presented. Key baseline measures of durability-related costs are summarized in Table 5-33, which appears at the end of Chapter 5. Chapter 6 concludes the document with a summary and suggestions for further research.

Since Section 3.3, Chapter 4, and Chapter 5 include statistics on a wide variety of durability-related issues, it is useful to first introduce three key concepts that should help readers interpret the meaning of these statistics. The three key concepts are: (1) the distinction between average household expenditures for improvements and for maintenance and repair in general and average household expenditures for specific building components and systems; (2) the assumed independence between the performance of individual building components and systems; and (3) the treatment of energy-related expenditures.

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[6] The following Federal Agencies are members of PATH: Department of Agriculture, Department of Commerce, Department of Energy, Department of Housing and Urban Development, Environmental Protection Agency, Federal Emergency Management Agency, National Science Foundation, Federal Housing Finance Board, and the White House Office of Science and Technology Policy. The Department of Housing and Urban Development is the PATH secretariat.

[7] Private sector members of PATH include representatives of builders, remodelers, and developers; housing manufacturers; product manufacturers; financial and insurance organizations; distributors and retailers; and university and research laboratories.

Durability-related expenditures fall under the categories of improvements and maintenance and repair activities. Improvements include: (1) additions (e.g., adding a new bedroom); alterations (e.g., kitchen remodeling); and major replacements (e.g., removing and replacing a hot water heater). Section 3.3 presents statistics for all types of improvements across all households. In 1997, these improvements totaled $92.4 billion or, on average, $888 per household. In any given year, many households do not undertake any improvements. Thus, the average cost for those households who do undertake improvements would be considerably more than $888. The same is true for maintenance and repair expenditures. In 1997, maintenance and repair expenditures averaged $395 per household. The statistics presented in Chapter 5 are based on cost information conditional on a specific type of improvement (e.g., kitchen remodeling) or maintenance and repair activity being undertaken. Thus, the statistics presented in Section 3.3 are estimates of average annual expenditures per household for improvements and maintenance and repair activities. For example, these figures could be used by a household to build a cash reserve for a future home improvement project. The statistics presented in Chapter 5 provide an indication of how much a specific home improvement activity or maintenance and repair activity would cost. Thus, the statistics presented in Chapter 5 correspond to averages of actual, one-time expenditures rather than average annual expenditures.

The service life data presented in Chapter 4 assume that the performance of individual building components and systems are independent. In light of the data sources currently available, treating building components and systems as independent is a reasonable assumption. However, there are instances where poor performance of one component can affect the performance of another. For example, moisture penetrating the building envelope can cause condensation in the attic or wall cavity, reducing the service life of interior and exterior finishes and the performance of attic or wall insulation. Thus, improper or no maintenance for selected building components could reduce the durability and/or performance of another building component or system. Therefore, the service life data presented in Chapter 4 are, whenever possible, expressed as ranges of values. The treatment of interdependencies between building components and systems is addressed in Section 6.2 as an area for additional research.

In 1997, the average household spent $1 338 on energy. Thus, energy-related expenditures represent a significant outlay for the typical household. Energy-related expenditures are affected by both generic housing characteristics (e.g., the size, age, and type of housing unit) and durability-related issues. For example, because of rising energy costs, households may decide to undertake improvement activities (e.g., replacing old or leaky single-glazed windows with double-glazed windows) or maintenance and repair activities (e.g., service contracts for the furnace and central air-conditioning system). In addition, the replacement of energy-related equipment (e.g., a furnace or central air-conditioning system) is a significant expense for the typical household. The decision to replace energy-related equipment has its roots both in its expected service life—a durability-related issue—expected replacement cost, and energy-related expenditures. Consequently, this report includes both information on the service life and expenditures

for energy-related equipment (see Section 4.2 and Subsections 5.2.1 and 5.2.2) and energy-related expenditures (see Section 3.3 and Subsection 5.2.4).

2. The Partnership for Advancing Technology in Housing

The Partnership for Advancing Technology in Housing (PATH) is a public/private initiative which seeks to speed the creation and widespread use of advanced technologies in order to improve the quality, durability, energy efficiency, environmental performance, and affordability of the Nation's housing. PATH is a voluntary partnership in which leaders of the home building, product manufacturing, and insurance and financial industries join forces with representatives of federal agencies concerned with housing. PATH is concerned with the following three goals: (1) developing new housing technologies; (2) disseminating information about new and existing housing technologies; and (3) studying and establishing mechanisms for sustained housing technology development. Through these goals, PATH seeks to spur housing industry design and construction change by providing the latest information on innovative building materials, processes and systems; showcasing innovative housing projects that can serve as models for builders and homeowners across the country; promoting focused, cooperative housing research among industry, government, and university partners; and tackling institutional barriers to innovation—from risk and liability concerns to the lack of effective product evaluation systems.

2.1 Description of the PATH Vision

During the next decade, PATH will encourage the development of innovative housing components, design and production methods and seek to reduce by 50 % the time needed to move quality technologies to market. These technologies will make it possible to produce housing that is affordable and attractive. By 2010, the adoption and use of these technologies is expected to achieve the PATH vision of improving housing:

(1) ***Affordability:*** reduce the monthly cost of new housing by 20 % or more;

(2) ***Energy-Efficiency and Environmental Protection:*** cut the environmental impact and energy use of new housing by 50 % or more and reduce energy use in at least 15 million existing homes by 30 % or more;

(3) ***Durability:*** improve durability and reduce maintenance costs by 50 %; and

(4) ***Disaster Resistance and Safety:*** reduce by at least 10 % the risk of loss of life, injury, and property destruction from natural hazards and decrease residential construction worker illnesses and injuries by at least 20 %.

To make the PATH vision operative, each component is based on the values of a well-defined set of baseline measures. The values of the baseline measures are averages of industry performance in 1997. The year 1997 was established as the basis for computing the values of the baseline measures because it was the year when the PATH goals were first formulated.

Expected results from PATH are increased housing affordability; increased durability; lower construction costs; improved energy efficiency; fewer construction injuries; less disaster losses; and accelerated development and increased market acceptance of new housing technologies. Finally, the PATH technology development and utilization process will help insure that the residential sector of the construction industry will remain a dynamic economic force far into the 21st Century.

2.2 Baseline Measures

As noted earlier, the baseline measures are averages of industry performance in 1997. Thus, with regard to the baseline measures, 1997 is the "base year." Consequently, data from 1997 drive this project's data collection effort, culminating with the development of the baseline measures for improving housing durability.

The process for developing baseline measures for improving housing durability used in this project involves: (1) specifying data relationships; (2) collecting and compiling the key data and supporting information for the base year, 1997; (3) defining metrics; and (4) producing the metrics in a tabular summary form and, where appropriate, producing charts and graphs to depict the metrics. This process is employed because the metrics represent not only a statement of current construction industry performance, but are useful in measuring an individual organization's performance as well. By providing a small set of well-defined metrics, individual organizations can use these definitions to construct their own performance baselines. For example, individual organizations can see how a collection of their projects performs vis-à-vis the "national" data. To summarize, the basic philosophy behind the baseline measures is that they are not a static concept whose sole purpose is quantifying the value of the PATH vision, but a means for driving performance improvement within individual organizations.

Criteria are needed to ensure that the data selected for analysis are well-defined, consistent, and replicable. Because data are so important to the baseline measures, BFRL reviewed many potential sources (e.g., journals, technical publications, and electronic media) of baseline-related data/information. This review suggested three criteria which must be met by any data in order to be accepted for analysis. These criteria are:

(1) Published by a reliable, nationally-recognized organization and available to the public;

(2) Updated on a regular basis; and

(3) Able to be normalized to account for changes in the building stock and the level of construction activity.

2.3 How the Baseline Measures Support the PATH Vision

As indicated earlier, the baseline measures are needed to monitor our success in achieving the PATH vision. Without baseline measures it is not possible to measure

progress towards improving housing durability. Stated another way: *Are we bridging the gap between the current state of performance and the desired level of performance?*

However, the baseline measures go beyond making the PATH vision operative. They result in a significant "spillover benefit" to the objectives of PATH. Since they are a valuable source of information on the current levels of industry performance, they can be used to guide interested parties on what might be expected values for service life of selected building materials or the costs of maintenance and repair activities, as well as the costs of major replacements (e.g., a complete roof replacement). Furthermore, since the baseline measures can be placed both within the context of a point estimate or a distribution of values, they can be incorporated as default values into decision support software to help potential users evaluate the life-cycle cost consequences of alternative investment decisions. Whenever distributional information on a particular metric is available, an even more powerful analytical tool for decision support software becomes possible. For example, if a distribution of replacement cost data for selected building elements is available, a potential software user could determine where their estimated replacement cost falls within the overall distribution for that building element.

On a deeper level, this document provides step-by-step descriptions of how to construct a well-defined set of baseline measures, their components, and associated metrics for improving durability and reducing maintenance costs in the Nation's stock of housing. Information on data classification, data sources, and data collection and analysis provide the underpinnings for the results presented in this document. It is anticipated that once users of this document have understood the vital role of baseline measures as a process improvement tool, they will see how the PATH vision will benefit both their organization and the U.S. construction industry.

3. Overview of Construction Industry Data

The construction industry is a key component of the U.S. economy and is vital to its continued growth. Investment in plants and facilities, in the form of construction activity, provides the basis for the production of products and the delivery of services. Investment in infrastructure promotes the smooth flow of goods and services and the movement of individuals. Investment in housing accommodates new households and allows existing households to expand or improve their housing. Clearly, construction activities affect nearly every aspect of the U.S. economy.[8]

This chapter provides a data-oriented snapshot of the U.S. construction industry. The chapter contains three sections. Each section deals with a particular topic. The topics progress from a general overview of construction expenditures for the construction industry as a whole to very specific statistics focusing on durability-related issues. This progression serves to define the context within which the baseline measures for improving housing durability are developed.

Section 3.1 presents information on the value of construction put in place to show the size of the construction industry and each of its four sectors. The four sectors, which taken together define the construction industry, are residential, commercial/institutional, industrial, and public works. Data from 1994 through 2000 are used to highlight the magnitude of construction-related investments in each sector. Data from 1997 are then used to establish the relative shares of construction-related investments for each sector. These data demonstrate that the residential sector accounts for approximately 45 % of the total value of all construction put in place.

Section 3.2 uses information on the residential sector both to focus on its importance within the overall construction industry and to define its key components. Information on investment activity is used to highlight the key components of residential construction. The nature of construction activity is then presented to differentiate expenditures that are investment-related (e.g., new construction, additions and alterations, and major replacements) versus those that are associated with day-to-day operations (e.g., maintenance and repair and energy).

Section 3.3 places special emphasis on identifying and detailing the key characteristics of housing. Information on the number of housing units by type of housing unit is used to classify units into key categories, some of which are used throughout the report (e.g., single-family detached). Information on durability-related expenditures is then presented. A series of tables is used to illustrate how expenditures vary across property types (i.e., owner-occupied or rental) and type of job (e.g., roof replacements). Next, a brief analysis of household expenditures for energy is presented. Expenditures by property type, fuel type (e.g., electricity), and end use (e.g., space heating) are used to

[8] Readers interested in learning more about construction statistics, their sources and interpretation, are referred to the document by Rogers (Rogers, R. Mark. 1994. *Handbook of Key Economic Indicators*. Burr Ridge, IL: Irwin Professional Publishing).

highlight different aspects of household expenditures for energy. The section concludes with a summary table in which selected cost data are presented.

3.1 Value of Construction Put in Place

This section provides information on a key indicator of construction activity—the value of construction put in place. Data published by the U.S. Bureau of the Census are used to establish the composition of construction expenditures by type of construction/function (e.g., residential/improvements). These expenditures are then assigned to the four key construction industry sectors. The reference document used throughout this section is the Current Construction Reports series C30 publication Value of Construction Put in Place.[9] A brief description of the "C30 report" follows. Special attention is given to the organization of the data in the C30 report and how these data map into the four key construction industry sectors. The section concludes with tabular and graphical summaries of the value of construction put in place.

Construction expenditures data are published monthly in the Current Construction Reports series C30 publication Value of Construction Put in Place. Construction expenditures refer to actual construction rather than planned or just initiated activity. It is noteworthy that the C30 report covers both private residential and non-residential construction activities and public sector construction activities.

The value of construction put in place is a measure of the value of construction installed or erected at a site during a given period. For an individual project, this includes: (1) cost of materials installed or erected; (2) cost of labor and a proportionate share of construction equipment rental; (3) contractor's profit; (4) cost of architectural and engineering work; (5) miscellaneous overhead and office costs chargeable to the project on the owner's books; and (6) interest and taxes paid during construction. Expenses do not include the cost of land nor do they include maintenance and repairs to existing structures or service facilities.

The C30 data are compiled via survey and through indirect estimation. In the context of the C30 survey, construction includes the following: (1) new buildings and structures; (2) additions, alterations, conversions, expansions, reconstruction, renovations, rehabilitations, and major replacements (e.g., the complete replacement of a roof or a heating system); (3) mechanical and electrical installations (e.g., plumbing, heating, electrical work, and other similar building services); (4) site preparation and outside construction of fixed structures or facilities (e.g., sidewalks, highways and streets, water supply lines, sewers, and similar facilities which are built into or fixed to the land); (5) installation of boilers, overhead hoists and cranes, and blast furnaces; (6) fixed, largely site-fabricated equipment not housed in a building (e.g., petroleum refineries and chemical plants); and (7) cost and installation of construction materials placed inside a building and used to support production machinery (e.g., concrete platforms, overhead steel girders, and pipes).

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[9] U.S. Department of Commerce. 2001. *Current Construction Reports: Value of Construction Put in Place. C30.* Washington, DC: U.S. Bureau of the Census.

The data presented in the C30 report are summarized in Tables 3-1 and 3-2. To facilitate comparisons between this report and the C30 report, Tables 3-1 and 3-2 use the same row and column headings as are used in the C30 report.

Tables 3-1 and 3-2 record annual values for the years 1994 through 2000. Table 3-1 records annual values in millions of constant 1997 dollars. Table 3-2 records annual values in millions of current dollars.[10] Reference to Table 3-1 reveals that total construction expenditures in real terms have increased modestly over the seven-year period (i.e., from $571.3 billion to $734.3 billion). When the effects of inflation are included, the rate of increase is more pronounced. Table 3-2 shows total construction expenditures in current dollars.

Tables 3-1 and 3-2 are organized to allow for in-depth analyses of the components/ subcomponents of total construction expenditures. To facilitate such analyses, the data presented in Tables 3-1 and 3-2 are initially divided into two parts: (1) private construction; and (2) public construction.

Private construction contains two major components—residential buildings and non-residential buildings—plus a number of subcomponents. Both the two major components and the various subcomponents are shown as headings in the first column of Tables 3-1 and 3-2.

The residential buildings component includes new private housing and improvements. New private housing includes new houses, apartments, condominiums, and town houses. New private housing units are classified as "1 unit" or "2 or more units." The value of improvements put in place are a direct measure of the value of residential additions and alterations activities and major replacements. The residential buildings component excludes residential units in buildings which are primarily non-residential. It also excludes mobile homes and houseboats.

The non-residential buildings component includes industrial, office buildings, hotels and motels, and "other commercial" (e.g., shopping centers, banks, service stations, warehouses, and other categories). Also falling under the non-residential buildings component are religious, educational, hospital and institutional, and "miscellaneous" non-residential buildings.

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[10] Inflation reduces the purchasing power of the dollar over time; deflation increases it. When amounts are stated in actual prices as of the year in which they occur, they are said to be in *current dollars*. Current dollars are dollars of any one year's purchasing power, inclusive of inflation/deflation. That is, they reflect changes in purchasing power of the dollar from year to year. In contrast, *constant dollars* are dollars of uniform purchasing power, exclusive of inflation/deflation. Constant dollars indicate what the same good or service would cost at different times if there were no change in the general price level to change the purchasing power of the dollar. For additional information on conducting economic analyses using either constant dollars or current dollars, see Fuller, Sieglinde K., and Stephen R. Petersen. 1996. *Life-Cycle Costing Manual for the Federal Energy Management Program*. NIST Handbook 135. Gaithersburg, MD: National Institute of Standards and Technology.

Table 3-1. Value of Construction Put in Place in Millions of Constant 1997 Dollars

Type of Construction	Millions of Constant (1997) Dollars						
	1994	1995	1996	1997	1998	1999	2000
Total Construction	**571 271**	**586 538**	**633 670**	**656 630**	**692 876**	**715 203**	**734 273**
Private Construction	**439 110**	**449 367**	**489 838**	**501 749**	**537 585**	**553 609**	**576 813**
Residential Buildings	262 659	261 129	290 341	289 014	306 260	326 447	337 030
New Housing Units	184 639	180 951	197 385	198 063	218 041	233 527	238 508
1 Unit	169 156	162 066	176 395	175 179	194 119	208 020	213 225
2 Units or more	15 483	18 885	20 991	22 883	23 922	25 507	25 282
Improvements	78 020	80 177	92 956	90 951	88 220	92 920	98 523
Nonresidential buildings	132 262	144 146	158 963	172 990	185 651	183 216	189 229
Industrial	31 829	35 919	37 409	36 739	39 410	32 655	28 881
Office	24 386	27 040	28 801	34 305	41 106	43 582	50 145
Hotel, motels	5 111	7 508	11 270	12 898	14 423	14 916	14 764
Other commercial	41 290	45 030	49 769	51 809	52 176	53 477	55 338
Religious	4 254	4 567	4 683	5 777	6 419	7 016	7 265
Educational	5 302	5 799	6 963	8 693	9 441	9 156	10 226
Hospital and institutional	13 490	11 875	12 167	13 546	13 427	12 750	13 125
Miscellaneous	6 600	6 409	7 901	9 223	9 249	9 664	9 485
Farm nonresidential	3 547	3 182	3 778	3 815	4 170	4 165	4 645
Public Utilities	37 464	37 856	34 244	33 638	38 966	37 066	43 299
Telecommunications	11 129	11 711	12 198	12 416	12 974	14 246	16 203
Other public utilities	26 335	26 145	22 047	21 222	25 992	22 820	27 095
Railroads	3 673	3 704	4 542	4 922	5 584	4 602	3 805
Electric light and power	16 403	14 832	11 579	11 325	12 053	13 155	19 010
Gas	5 161	6 629	4 877	4 006	7 124	3 669	3 377
Petroleum pipelines	1 097	981	1 048	969	1 231	1 393	903
All other private	3 178	3 054	2 511	2 292	2 537	2 715	2 611
Public Construction	**132 161**	**137 170**	**143 833**	**154 882**	**155 291**	**161 595**	**157 460**
Buildings	54 370	60 971	65 554	71 867	71 333	72 706	74 088
Housing and redevelopment	4 217	4 960	5 214	5 230	4 988	5 258	4 708
Industrial	1 611	1 592	1 435	999	983	866	1 044
Educational	22 388	27 219	29 528	34 385	35 273	37 176	39 225
Hospital	4 344	4 472	4 769	5 152	3 802	3 713	3 608
Other	21 809	22 727	24 608	26 100	26 288	25 693	25 503
Highways and streets	41 145	39 711	40 759	44 105	47 228	50 098	46 905
Military facilities	2 549	3 179	2 676	2 556	2 462	1 976	2 104
Conservation and development	6 997	6 659	6 205	5 739	5 302	5 618	5 416
Sewer systems	9 566	8 889	10 120	10 392	9 898	10 464	9 263
Water supply facilities	5 110	4 971	5 802	6 419	6 649	7 114	6 239
Miscellaneous public	12 426	12 791	12 717	13 803	12 417	13 621	13 444

Table 3-2. Value of Construction Put in Place in Millions of Current Dollars

Type of Construction	Millions of Current Dollars						
	1994	1995	1996	1997	1998	1999	2000
Total Construction	**519 539**	**555 591**	**613 535**	**656 630**	**711 759**	**764 233**	**815 414**
Private Construction	**399 346**	**425 658**	**474 273**	**501 749**	**552 236**	**591 561**	**640 554**
Residential Buildings	238 874	247 351	281 115	289 014	314 607	348 826	374 274
New Housing Units	167 919	171 404	191 113	198 063	223 983	249 536	264 864
1 Unit	153 838	153 515	170 790	175 179	199 409	222 280	236 788
2 Units or more	14 081	17 889	20 324	22 883	24 574	27 256	28 076
Improvements	70 955	75 947	90 002	90 951	90 624	99 290	109 410
Nonresidential buildings	120 285	136 541	153 912	172 990	190 711	195 776	210 140
Industrial	28 947	34 024	36 220	36 739	40 484	34 894	32 073
Office	22 178	25 613	27 886	34 305	42 226	46 570	55 686
Hotel, motels	4 648	7 112	10 912	12 898	14 816	15 939	16 396
Other commercial	37 551	42 654	48 188	51 809	53 598	57 143	61 453
Religious	3 869	4 326	4 534	5 777	6 594	7 497	8 068
Educational	4 822	5 493	6 742	8 693	9 698	9 784	11 356
Hospital and institutional	12 268	11 248	11 780	13 546	13 793	13 624	14 575
Miscellaneous	6 002	6 071	7 650	9 223	9 501	10 327	10 533
Farm nonresidential	3 226	3 014	3 658	3 815	4 284	4 451	5 158
Public Utilities	34 071	35 859	33 156	33 638	40 028	39 607	48 084
Telecommunications	10 121	11 093	11 810	12 416	13 328	15 223	17 994
Other public utilities	23 950	24 766	21 346	21 222	26 700	24 384	30 089
Railroads	3 340	3 509	4 398	4 922	5 736	4 918	4 226
Electric light and power	14 918	14 049	11 211	11 325	12 381	14 057	21 111
Gas	4 694	6 279	4 722	4 006	7 318	3 920	3 750
Petroleum pipelines	998	929	1 015	969	1 265	1 489	1 003
All other private	2 890	2 893	2 431	2 292	2 606	2 901	2 899
Public Construction	**120 193**	**129 933**	**139 263**	**154 882**	**159 523**	**172 673**	**174 860**
Buildings	49 446	57 754	63 471	71 867	73 277	77 690	82 275
Housing and redevelopment	3 835	4 698	5 048	5 230	5 124	5 618	5 228
Industrial	1 465	1 508	1 389	999	1 010	925	1 159
Educational	20 361	25 783	28 590	34 385	36 234	39 725	43 560
Hospital	3 951	4 236	4 617	5 152	3 906	3 968	4 007
Other	19 834	21 528	23 826	26 100	27 004	27 454	28 321
Highways and streets	37 419	37 616	39 464	44 105	48 515	53 532	52 088
Military facilities	2 318	3 011	2 591	2 556	2 529	2 111	2 337
Conservation and development	6 363	6 308	6 008	5 739	5 447	6 003	6 014
Sewer systems	8 700	8 420	9 798	10 392	10 168	11 181	10 287
Water supply facilities	4 647	4 709	5 618	6 419	6 830	7 602	6 928
Miscellaneous public	11 301	12 116	12 313	13 803	12 755	14 555	14 930

Rounding out the private construction component are farm non-residential, public utilities, and "all other private." These are generally of a non-residential nature, but are not part of non-residential buildings. Farm non-residential construction includes structures such as barns, storage houses, and fences. Land improvements such as leveling, terracing, ponds, and roads are also a part of this subcomponent. Privately owned public utilities construction is categorized by industry rather than function of the building or structure. This subcomponent includes expenditures made by utilities for telecommunications, railroads, petroleum pipelines, electric light and power, and natural gas. "All other private" includes privately owned streets and bridges, sewer and water facilities, airfields, and similar construction.

For public construction, there is one major component—building—and six components that are classified collectively as "non-building." The building major component contains subcomponents similar to those for private construction, with educational buildings being the largest subcomponent. Expenditures for the "non-building" components overwhelmingly consist of outlays for highways and streets, with sewer systems being a distant second component.

To get the sector totals, each subcomponent was assigned to a sector and summed. The sector assignments are identical to those used in Chapman and Rennison.[11] The sector totals and the overall total are recorded in Tables 3-3 and 3-4. Reference to the tables reveals that sector totals vary considerably, with residential being the largest and industrial the smallest.

Table 3-3. Value of Construction Put in Place: Sector Totals and Sum Total in Millions of Constant 1997 Dollars[12]

Sector	Value of Construction Put in Place ($ Millions)						
	1994	1995	1996	1997	1998	1999	2000
Residential	266 876	266 089	295 555	294 244	311 248	331 705	341 738
Commercial/ Institutional	152 521	165 828	184 237	205 703	215 774	221 308	233 329
Industrial	33 440	37 511	38 844	37 738	40 393	33 521	29 925
Public Works	118 434	117 111	115 034	118 944	125 459	128 671	129 280
Total - All Sectors	571 271	586 539	633 670	656 629	692 874	715 205	734 272

[11] Chapman, Robert E., and Roderick Rennison. 1998. *An Approach for Measuring Reductions in Operations, Maintenance, and Energy Costs: Baseline Measures of Construction Industry Practices for the National Construction Goals*. NISTIR 6185. Gaithersburg, MD: National Institute of Standards and Technology.

[12] Note that due to rounding the values entered in the "Total – All Sectors" row in Table 3-3, differ slightly from the values entered in the "Total Construction" row in Table 3-1.

Table 3-4. Value of Construction Put in Place: Sector Totals and Sum Total in Millions of Current Dollars[13]

Sector	Value of Construction Put in Place ($ Millions)						
	1994	1995	1996	1997	1998	1999	2000
Residential	242 709	252 049	286 163	294 244	319 731	354 444	379 502
Commercial/ Institutional	138 710	157 078	178 383	205 703	221 654	236 482	259 113
Industrial	30 412	35 532	37 609	37 738	41 494	35 819	33 232
Public Works	107 709	110 932	111 379	118 944	128 878	137 492	143 567
Total - All Sectors	519 540	555 591	613 534	656 629	711 757	764 237	815 414

Table 3-3 reveals that the residential and commercial/institutional sectors have grown fairly consistently in real terms over the entire seven-year period. In real terms, expenditures in the residential sector grew from $266.9 billion in 1994 to $341.7 billion in 2000, an increase of almost 30 %. Real expenditures for two of the four sectors, industrial and public works, were essentially constant over the same seven-year period.

The data contained in Tables 3-3 and 3-4 provide the basis for calculating each sector's relative share of total construction expenditures. Each sector's relative share of total construction expenditures is shown graphically in pie chart form in Figure 3-1. It was constructed using 1997 data from Table 3-4 (i.e., current dollar expenditures). Figure 3-1 reveals that in 1997 the residential sector accounted for 45 percent of total construction expenditures (i.e., 45 % of $656.6 billion).

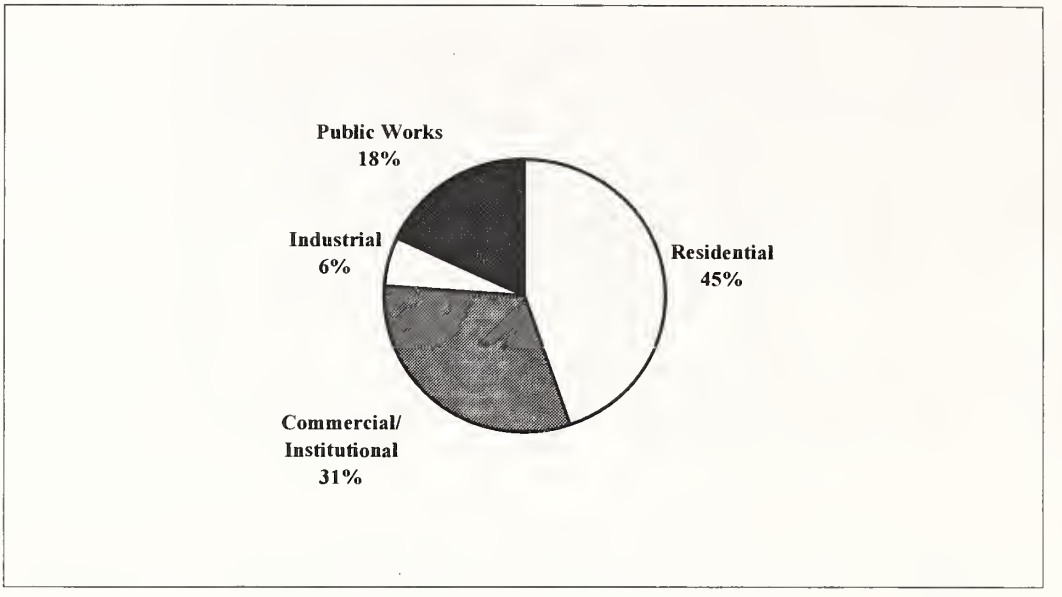
3.2 Overview of the Residential Sector

The residential sector, defined in economic terms, consists of residential buildings. A residential building is a structure used primarily as a dwelling for one or more households. Residential buildings include single-family detached and single-family attached dwellings, apartments, and condominiums.

Expenditures by or for households in the residential sector include construction expenditures (e.g., new construction, additions and alterations, and major replacements) as well as expenditures for building operations, for maintenance and repair activities, and for energy. Consequently, it is instructive to first define what is included in each type of expenditure and then examine the characteristics of residential buildings that affect these expenditures.

[13] Note that due to rounding the values entered in the "Total-All Sectors" row in Table 3-4 differ slightly from the values entered in the "Total Construction" row of Table 3-2.

Figure 3-1. 1997 Breakdown of $656.6 Billion Construction Market



Residential construction expenditures include both new construction activities and improvements, where improvements include both additions and alterations and major replacements.

> *New construction* activities include the complete original residential building and essential service facilities and the initial installation of integral equipment (e.g., plumbing, heating, and air-conditioning supplies and equipment).
>
> *Improvements—additions and alterations and major replacements*—include construction work that adds to the value or useful life of an existing residential building or structure, or which adapts a building or structure to residential use. Included are major replacements of building systems (e.g., installation of a new roof or heating system).

Building operations for the residential sector include all activities required to operate a building (e.g., water consumption and trash removal), with the exception of maintenance and repair activities and energy. Fixed residential building operations components are also included (e.g., principal and interest payments, real estate and other taxes, and insurance) under this expenditure category.[14]

[14] Although building operations for the residential sector are defined for purposes of completeness, they are considered to be beyond the purview of this report and, consequently, will not be covered in the baseline measures presented in the following two chapters.

Maintenance and repair activities include incidental construction work that keeps a residential building or structure in ordinary working condition.

Energy is defined to encompass all energy consumption required to support occupant activities in a residential building. Energy consumption can be categorized by energy source (e.g., electricity, natural gas, and fuel oil) and by end-use (e.g., space heating, air-conditioning, appliances, and lighting).

Expenditure data for the residential sector are available from a variety of sources. The C30 report is designed to capture construction expenditure data for the industry as a whole as well as the residential sector. The residential sector receives special attention in the C30 report because it separates private residential construction expenditure data into new construction and improvements. The Census also publishes several other reports based on survey data. These include the Census of the Construction Industry, conducted every five years in years ending in 2 and 7, and the quarterly C50 report—Expenditures for Residential Improvements and Repairs. In addition, the Census conducts the American Housing Survey (AHS) to obtain up-to-date housing statistics for the U.S. Department of Housing and Urban Development (HUD). Finally, the U.S. Department of Energy (DOE) conducts the Residential Energy Consumption Survey (RECS) which provides information on the use of energy in residential housing units in the United States.

Because the focus of this section is providing an overview of the residential sector, only 1997 data from the C30 report and the Census of the Construction Industry will be presented. The following section—Characteristics of Housing—will include 1997 data from the AHS, the C50 report, and the RECS.

Based on data published in the C30 report—Value of Construction Put in Place—construction expenditures in 1997 for the residential sector were $294.2 billion in current dollars (see Table 3-4). Total expenditures include expenditures from subcomponents listed under both the "private construction" and "public construction" headings in Tables 3-1 and 3-2. The three subcomponents included under the private construction heading are: (1) New Housing Units—1 Unit; (2) New Housing Units—2 Units or More; and (3) Improvements. The subcomponent included under the public sector heading is Public Housing and Redevelopment. The relative share of the overall residential sector's construction expenditures for each of the four key subcomponents is shown graphically in pie chart form in Figure 3-2. It was constructed using 1997 data from Table 3-2 (i.e., current dollar expenditures). Reference to Figure 3-2 reveals that in 1997 the New Housing Units—1 Unit subcomponent accounted for 59 % of the residential sector's construction expenditures and the Improvements subcategory accounted for 31 %.

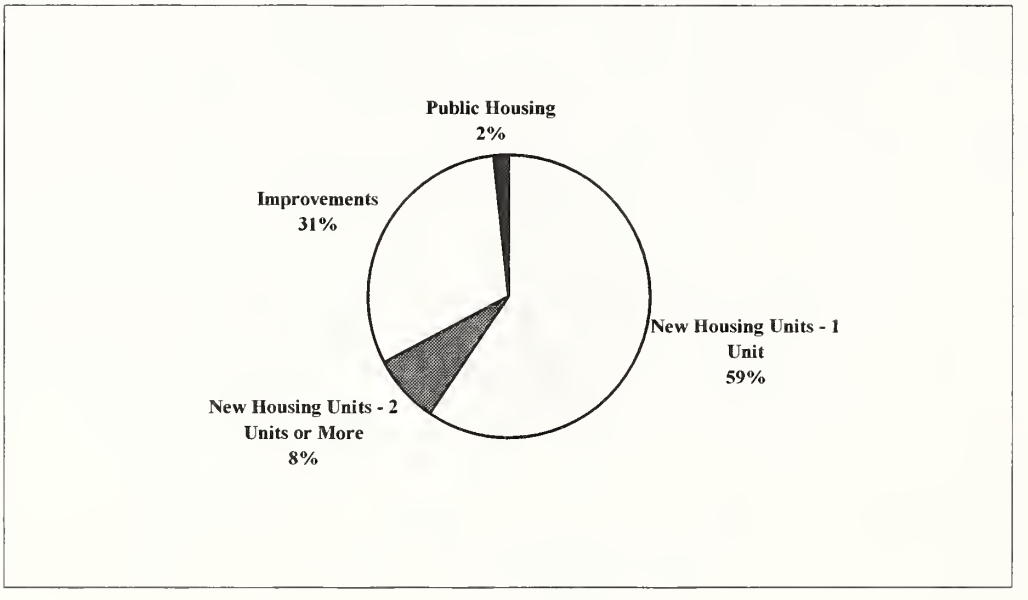
The 1997 Census of the Construction Industry focuses both on the industry as a whole, as well as the key subsectors. For purposes of this study, the 1997 Census of the Construction Industry includes both an industry summary[15] and separate reports on

[15] U.S. Department of Commerce. 2000. *Industry Summary: 1997 Economic Census, Construction Subject Series*. EC97C23S-IS. Washington, DC: U.S. Census Bureau.

single-family[16] and multi-family housing.[17] The Census of the Construction Industry enumerates construction establishments with paid employees. At the time of the 1997 census, there were about 1.5 million construction establishments, of which 656 448 had paid employees. Establishments without payroll, typically one-person operations or partnerships, are not surveyed in the Census of the Construction Industry.

Construction work covered by the 1997 census includes new construction, additions, alterations, and repairs. Establishments identified as construction management firms are also included. The Census of the Construction Industry divides construction into three sectors: (1) building, developing, and general contracting; (2) heavy construction; and (3) special trade contractors.

Figure 3-2. 1997 Breakdown of $294.2 Billion Residential Sector



The value of residential construction work for establishments with employees as tabulated in the 1997 Census of the Construction Industry is reported in Table 3-5. The table summarizes expenditure information for three types of residential construction: (1) single-family homes; (2) apartment buildings; and (3) all other residential buildings. Four types of expenditure information are reported for each type of construction: (1) new construction; (2) additions, alterations, and reconstruction; (3) maintenance and repair; and (4) total. The second type of construction expenditure—additions, alterations, and reconstruction—corresponds to improvements as published in the C30 report. Comparisons between Tables 3-2 and 3-5 reveal good agreement on the total values of expenditures for new construction and for the individual components single-family

[16] U.S. Department of Commerce. 1999. *Single-Family Housing Construction: 1997 Economic Census, Construction Industry Series.* EC97C-2332A(RV).
[17] U.S. Department of Commerce. 1999. *Multi-Family Housing Construction: 1997 Economic Census, Construction Industry Series.* EC97C-2332B(RV).

housing and apartment buildings. Comparisons between Tables 3-2 and 3-5, however, reveal significant differences between expenditures for residential improvements as published in the C30 report—$91.0 billion—and the comparable type of expenditure published in the 1997 Census of the Construction Industry—$46.4 billion. The likely cause of this discrepancy is that the Census of the Construction Industry only enumerates construction establishments with paid employees. Because such a large proportion of construction establishments are without paid employees, many of the smaller construction jobs are not covered in the 1997 census.[18] It is likely that a great deal of this work falls into the expenditure categories of improvements and maintenance and repair. Thus, to get a more accurate view of the total scope of construction expenditures for improvements and for maintenance and repair, other sources of information must be considered. These sources are the focus of section 3.3.

Table 3-5. Expenditures in Millions of Dollars for Establishments with Payroll by Type of Construction: 1997

Type of Construction	Type of Expenditure			
	New Construction	Additions, Alterations, Reconstruction	Maintenance & Repair	Total
Single-Family Houses	179 326	38 743	20 233	238 302
Apartment Buildings	23 549	7 294	5 069	35 912
All other Residential Buildings	880	410	161	1,451
Total	203 755	46 447	25 463	275 665

3.3 Characteristics of Housing

This section uses published information from three key surveys covering the residential sector—the AHS, the C50 report, and the RECS—to arrive at a summary of the characteristics of housing and to present information on expenditures for improvements, maintenance and repair activities, and energy. Background information on each data source is first presented followed by a description and analysis of selected data elements. The section concludes with a summary table where key types of expenditures are reported. Data sources for the key types of expenditures are also reported.

AHS — American Housing Survey

The AHS is conducted by field representatives who obtain information from occupants of homes. They get information on vacant homes from informed people such as landlords, rental agents, or knowledgeable neighbors. The 1997 national survey was conducted from August 1997 through November 1997. This national sample of about 53 000

[18] This issue was discussed at the Construction Statistics Data Users' Conference held in 1997. The goal of the conference was to generate suggestions for improving Census' statistics on the construction industry. For additional information on the conference and the recommendations it produced, see U.S. Department of Commerce. 1999. *Construction Statistics Data Users' Conference.* Washington, DC: Bureau of the Census.

interviews is conducted every other year. From 1973, when it started, to 1981, the AHS collected national data every year, instead of every other year, and was called the Annual Housing Survey.

The AHS is issued jointly by HUD's Office of Policy Development and Research and the U.S. Census Bureau. The published report of the 1997 AHS[19] presents data on apartments, single-family homes, mobile homes, and vacant housing units. The AHS also tabulates information according to housing costs, equipment and fuels, size of the housing units, and year of construction. The 1997 AHS also tabulates information on mortgages, household income, and age, gender, and race of householders.

The 1997 AHS data are also available as a set of public-access files. These files permit the data tabulated in the published report to be "sliced and diced" in a variety of ways. These additional "data classifications" are presented and discussed in Chapter 5, where they provide the basis for most of the baseline measures for durability-related costs.

The material from the 1997 AHS presented in this section focuses on laying out the key characteristics of the Nation's stock of housing units. This material is presented in Table 3-6. The table records the number of housing units for each type of tenure class (i.e., whether the unit is occupied or unoccupied, and, if occupied, whether it is occupied by the owner or a renter). Reference to Table 3-6 reveals that in 1997 there were 112.4 million housing units in the United States. Of these, 99.5 million were occupied and 12.9 million were unoccupied. At first blush, 12.9 million unoccupied housing units seems excessive. However, nearly 25 % of all unoccupied units are intended for seasonal use by the owner (i.e., to be occupied during only certain seasons of the year). Seasonal units are not anyone's usual residence. Of the 9.7 million vacant units, 29 % are held for weekend or occasional use throughout the year. Another 29 % of the units listed as vacant are for rent, 11 % are for sale, and 8 % have been rented or sold but not yet occupied. Finally, 23 % of the vacant units are held for settlement of an estate, held for occupancy by a caretaker, or held for personal reasons of the owner.

The 99.5 million occupied units are subdivided into two tenure classes: owner and renter. Approximately two-thirds of all occupied housing units—65.5 million—are occupied by owners and one-third—34.0 million—are occupied by renters. Reference to Table 3-6 reveals that more than 80 % of all units occupied by the owner are single-family detached dwellings. Approximately 25 % of all units occupied by a renter are single-family detached dwellings. Table 3-6 also records information on the 8.3 million mobile homes in the United States. 6.5 million mobile homes are occupied and 1.8 million are unoccupied. Approximately 80 % of all occupied mobile homes are occupied by the owner. Multi-family units are occupied primarily by a renter. For example, slightly more than 20 % of all units occupied by a renter are multi-family, 2 to 4 unit, residential buildings.[20]

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[19] U.S. Department of Housing and Urban Development. 1999. *American Housing Survey for the United States: Current Housing Reports*. H150/97. Washington, DC: Office of Policy Development and Research.

[20] The 1997 AHS also tabulates information on the 7.7 million cooperatives and condominiums in the United States. Cooperative and condominium ownership may apply to various types of structures including

Table 3-6 Characteristics of Housing Units: 1997

Type of Housing Unit	Tenure Class					
	Total Housing Units	Occupied			Unoccupied	
		Total	Owner	Renter	Vacant	Seasonal
Single-Family Detached	68 109	62 111	53 756	8 355	4 167	1 831
Single-Family Attached	6 778	5 840	3 030	2 810	781	157
Multi-Family, 2 to 4 units	10 363	8 973	1 756	7 216	1 261	129
Multi-Family, 5 to 9 units	5 657	4 852	491	4 361	727	78
Multi-Family, 10 to 19 units	5 025	4 264	319	3 945	702	59
Multi-Family, 20 to 49 units	3 877	3 292	355	2 936	509	75
Multi-Family, 50 or more units	4 247	3 611	524	3 087	528	108
Mobile Home or Trailer	8 301	6 544	5 255	1 289	1 028	729
Total	112 357	99 487	65 487	34 000	9 704	3 166

C50 Report — Expenditures for Residential Improvements and Repairs

The C50 report provides estimates of expenditures by property owners for construction improvements (additions, alterations, and major replacements) and maintenance and repairs to residential properties. The data presented in the C50 report are compiled from two sources: (1) a household survey of a sample of consumer units; and (2) a mail survey of owners of a sample of rental or vacant properties.

The household survey is based on personal interviews obtained from household members as part of the consumer expenditure surveys that the Census performs for the Bureau of Labor Statistics. The consumer expenditure surveys are designed to collect data on major items of consumer expense, household characteristics, and income. The expenditures covered by the survey are those that respondents can be expected to recall fairly accurately for three months or longer, including expenditures for maintenance and repairs and improvements of properties. Each sample household is interviewed once per quarter for five consecutive quarters. The number of interviews per quarter is targeted at 5 000.

The mail survey covers non-resident owners of rental or vacant properties containing one to four housing units and owners of rental or vacant properties containing five housing units or more. Non-resident owners are mailed a questionnaire to report detailed maintenance and repair and improvement expenditures for their properties. Approximately 3 000 non-resident owners are queried each quarter.

The C50 data cover single and multi-unit structures, publicly and privately owned structures, non-farm and farm properties, and residential properties that are occupied by

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single-family detached dwellings, single-family-attached dwellings, as well as apartments. Separate figures for cooperatives and condominiums are not recorded in Table 3-6 so as to avoid double counting. Of the 5.9 million cooperatives and condominiums that are occupied, 60 % are occupied by the owner and 40 % are occupied by a renter.

owners or renters or are vacant. Excluded are: (1) properties classified as primarily non-residential; (2) residential structures on the grounds of institutions, schools, armed forces installations, etc.; (3) hotels, motels, tourist cabins, and boarding houses; and (4) manufactured homes and unusual living quarters (e.g., house boats).

The expenditures covered in the C50 report are those connected with construction activity intended to maintain or improve the property. As a general principle, expenses connected with items not permanently attached or firmly affixed to some part of the housing unit or property are not included. Thus, expenses connected with the repair or replacement of household appliances (e.g., stoves and refrigerators) are excluded as are costs connected with household furnishings (e.g., furniture, rugs, and draperies). While the cost of appliances is excluded, the construction cost of building-in such appliances (e.g., the cost of building-in a wall oven) is included within the scope of the C50 report. Everyday household and housekeeping expenses (e.g., cleaning floors, walls, and windows) are excluded. Expenditures for grading, draining, fencing, and paving are included but the costs of landscaping (e.g., planting trees, shrubs, and flowers) are not included in the C50 report. A brief description of the types of expenditures covered in the C50 report under the categories of improvements and maintenance and repair activities is used to set the stage for the tables which follow.

Expenditures for residential improvements are capital expenditures that add to the value or useful life of the property. Since the classification of residential improvements used in the C50 report—and in the C30 report—is based on the concept of additions, alterations, and major replacements rather than dollar value, some very small expenditures that may not be considered capital investments are included under the residential improvements category (e.g., installation of a new electrical socket or garbage disposal). Residential improvements cover additions to residential structures (e.g., adding a room), alterations within residential structures (e.g., from complete remodeling to the installation of an electrical service outlet), additions and alterations on properties outside residential structures (e.g., detached garages, sheds, patios, and fences), and major replacements (e.g., replacement of the entire roof). In general, the distinction between major replacements and additions and alterations is that major replacements are substitutions. Installation of a bathtub, where there had not been one before, is an alteration, but the substitution of a new bathtub for an old one is a major replacement.

Maintenance and repair expenditures represent current costs for incidental maintenance and repair activities that keep a property in ordinary working condition, rather than an additional investment in the property. Maintenance includes such expenses as painting, papering, floor sanding, and furnace cleaning or adjustment. Repairs include many kinds of expenditures for plumbing, heating, electrical work, and other kinds of activity involved in the upkeep of residential properties. Repairs also include replacements of parts and of whole units, except for a select list specified below that are classified as major replacements.[21] For example, roof repairs—including replacement of shingles and

[21] The following is a list of items that, when replaced, are considered to be major replacements as opposed to repairs: complete furnace or boiler, entire roof, central air-conditioner, all siding, water heater, entire

gutters—are classified under the maintenance and repair expenditure category, but a complete reroofing is classified as a major replacement. Plumbing repairs may include extensive replacement of water pipes, but if the entire piping system is removed and a new one put in, the expenditures for the work are classified as major replacements. Maintenance and repairs do not include expenses for trash and snow removal, lawn maintenance and landscaping, or cleaning and janitorial services.

Table 3-7 records expenditures for improvements and for maintenance and repair activities by tenure class and type of housing unit. Table 3-7 is divided into two parts. Part A records expenditures in millions of 1997 dollars. The information recorded in Part A is taken directly from the C50 report. Part B records information on estimated average expenditures per housing unit in 1997 dollars. Part B uses the information recorded in Part A and information from Table 3-6 on the number of housing units by tenure class to empirically estimate the "national" average expenditure per housing unit.

Part A of Table 3-7 records for each tenure class—owner-occupied and rental—total expenditures and expenditures for selected types of housing units in millions of 1997 dollars. The table also records the combined total across both tenure classes under the heading All Residential Properties. Information for improvements, maintenance and repair, and combined total expenditures are recorded on separate rows of the table. Reference to Part A of Table 3-7 reveals that expenditures for improvements totaled $92.4 billion and expenditures for maintenance and repair activities totaled $41.1 billion. The combined total for both improvements and maintenance and repairs was $133.6 billion.[22] Approximately two-thirds of all expenditures—$94.0 billion—are for owner-occupied units and one-third—$39.6 billion—are for rental units. Reference to Part A of the table reveals that more than 95 % of total expenditures for owner-occupied units occur in single-family dwellings. The distribution of expenditures in rental units differs from those in owner-occupied units. Reference to the table reveals that expenditures in single-family rental units amount to approximately 55 % of the total and expenditures in multi-family dwellings with 5 units or more amount to approximately 35 % of the total.

Part B of Table 3-7 combines information from the AHS (see Table 3-6) with total expenditure information (see Part A) to construct a "national" estimate of expenditures per housing unit measured in 1997 dollars. This calculation is facilitated by recognizing that the C50 report combines information on unoccupied housing units (i.e., vacant and seasonal) into the rental tenure class. Similarly, since the types of housing units are aggregates of the entries in Table 3-6, they can be mapped into the property types recorded in Table 3-7 to create a denominator for each cell in Part A of Table 3-7 that can be used to produce an estimated average value of expenditures per housing unit. Note that mobile homes have been removed from the calculations performed in Part B because they are not covered in the C50 report. Expenditures per housing unit range from a high of $1 597 for single-family, owner-occupied dwellings to a low of $478 for multi-family rental dwellings with 2 to 4 units. The values reported in Part B are "unconditional"

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electrical wiring, doors, plumbing fixtures, all water pipes, windows, septic tank or cesspool, sink or laundry tub, complete walks or drive ways, and garbage disposal unit.

[22] Due to rounding, the totals in both Parts A and B may not be equal to the sum of the constituent parts.

since they include housing units that made no expenditures for either improvements or for maintenance and repair activities. "Conditional" estimates are covered in Chapter 5, where estimates are derived based on AHS data reported from units that performed specific improvement or maintenance and repair activities.

Table 3-8 reports expenditures in millions of 1997 dollars by tenure class and type of job. The table shows both total expenditures and expenditures for improvements and for maintenance and repair activities. Improvements are subdivided into additions, alterations, outside additions and alterations, and major replacements. Each of these subdivisions is further subdivided into their constituent parts (i.e., specific job types). Maintenance and repair activities are similarly subdivided into their constituent parts. In all, 28 specific job types are reported for the improvements category and 10 specific job types are reported for maintenance and repair activities.

Table 3-8 provides a fairly detailed picture of how expenditures vary across tenure class and job type. For example, the largest components of improvements are alterations and major replacements. Among owner-occupied units, kitchen remodeling, other alterations, and bathroom remodeling are the largest specific job types of the alterations component, resulting in expenditures of $5.1 billion, $4.7 billion, and $3.3 billion, respectively. The three largest specific job types of major replacements component for owner-occupied units are roofing, HVAC, and the combination of windows and doors, resulting in expenditures of $5.5 billion, $4.6 billion, and $4.0 billion, respectively. Among rental units, the two largest alterations components are other alterations—$2.3 billion—and kitchen and bath remodeling—$1.6 billion. For maintenance and repair activities, expenditure patterns between owner-occupied units and rental units are similar in their top rankings, with expenditures for painting and papering first, followed by other maintenance and repair activities, roofing, and plumbing.

Table 3-9 records expenditures for improvements and for maintenance and repair activities by tenure class and type of payment for owner-occupied one-unit properties. Table 3-9 is divided into two parts. Part A records expenditures in millions of 1997 dollars. The information recorded in Part A is taken directly from the C50 report. Part B records information on estimated average expenditures per housing unit in 1997 dollars. Part B uses the information recorded in Part A and information from Table 3-6 on the number of housing units by tenure class to empirically estimate the "national" average expenditure per housing unit.

Part A records total expenditures for improvements, maintenance and repair activities, and their combined total for each of three types of expenditures; it also includes two sets of totals, one for building materials purchased by the owner and one for all payments. Although Table 3-9 only covers expenditures for owner-occupied, one-unit properties, these properties represent two-thirds of all expenditures (i.e., $90.7 billion out of $133.6 billion). Reference to Part A reveals that more than 20 % of total expenditures are for building materials purchased by the owner occupant. Almost 80 % of building materials purchased by the owner occupant are for jobs done by the owner.

Table 3-7 Expenditures for Improvements and Maintenance and Repair Activities by Tenure Class and Type of Housing Unit: 1997

Part A: Total Expenditures in Millions of 1997 Dollars

Type of Expenditure	Tenure Class and Type of Housing Unit							
	All Residential Properties	Owner - Occupied			Rental			
		Total	1 Unit	2 units or more	Total	1 Unit	2 to 4 Units	5 units or more
Improvements	92 432	66 635	64 467	2 168	25 797	16 231	2 200	7 366
Maintenance & Repair	41 145	27 328	26 210	1 118	13 817	5 530	1 913	6 374
Total	133 577	93 962	90 677	3 285	39 615	21 761	4 113	13 741

Part B: Estimated Average Annual Expenditures Per Housing Unit in 1997 Dollars

Type of Expenditure	Tenure Class and Type of Housing Unit							
	All Residential Properties	Owner - Occupied			Rental			
		Total	1 Unit	2 units or more	Total	1 Unit	2 to 4 Units	5 units or more
Improvements	888	1 106	1 135	629	589	897	256	430
Maintenance & Repair	395	454	462	325	315	306	222	372
Total	1 284	1 560	1 597	954	904	1 202	478	803

Table 3-8. Expenditures in Millions of Dollars by Tenure Class and Type of Job: 1997

Type of Job	Tenure Class		
	Owner-Occupied	Rental	Total
Total Expenditures	**93 962**	**39 615**	**133 577**
Improvements	**66 635**	**25 797**	**92 432**
Additions	12 057	2 518	14 575
decks & porches	2 911	1 374	4 285
attached garages	472	173	645
rooms	8 674	972	9 646
Alterations	26 566	10 560	37 126
plumbing	1 587	1 355	2 942
HVAC	1 952	1 146	3 098
electrical	556	705	1 261
flooring	2 573	1 219	3 792
kitchen remodeling	5 064	#	5 064
bathroom remodeling	3 281	#	3 281
kitchen & bath remodeling	171	1 625	1 796
finishing space	1 216	$	1 216
interior restructuring	3 639	1 429	5 068
siding	1 164	$	1 164
windows & doors	620	797	1 417
other alterations	4 741	2 282	7 023
Outside Additions & Alterations	9 805	3 718	13 523
detached buildings	3 235	703	3 938
patios & terraces	1 357	$	1 357
driveways & walkways	1 240	$	1 240
fences	1 564	310	1 874
other outside additions & alterations	2 409	2 705	5 114
Major Replacements	18 206	9 004	27 210
plumbing	1 555	1 563	3 118
HVAC	4 603	1 489	6 092
siding	1 105	$	1 105
roofing	5 450	2 635	8 085
driveways & walkways	551	$	551
windows	2 959	1 301	4 260
doors	1 008	374	1 382
other major replacements	975	1 640	2 615
Maintenance & Repair	**27 328**	**13 817**	**41 145**
painting & papering	7 958	4 090	12 048
plumbing	2 687	1 676	4 363
HVAC	1 411	722	2 133
electrical	516	593	1 109
siding	725	463	1 188
roofing	2 735	2 701	5 436
flooring	1 681	776	2 457
windows & doors	875	584	1 459
materials to have on hand	2 796	287	3 083
other maintenance & repair	5 943	1 925	7 868

Expenditures included in the "Kitchen and Bathroom Remodeling" category.

$ Expenditures included in the "Other" category.

Table 3-9. Expenditures for Owner-Occupied One-Unit Properties by Type of Payment: 1997

Part A: Total Expenditures in Millions of 1997 Dollars

Type of Expenditure	Type of Payment				
	All Payments	Payments to Contractors & Hired Labor	Building Materials Purchased by Owner		
			Total	For Jobs done by Owner	For Jobs done under Contract
Improvements	64 467	50 987	13 480	9 963	3 517
Maintenance & Repair	26 210	19 453	6 757	5 926	831
Total	90 677	70 440	20 236	15 888	4 348

Part B: Estimated Average Annual Expenditures Per Housing Unit in 1997 Dollars

Type of Expenditure	Type of Payment				
	All Payments	Payments to Contractors & Hired Labor	Building Materials Purchased by Owner		
			Total	For Jobs done by Owner	For Jobs done under Contract
Improvements	1 135	898	237	175	62
Maintenance & Repair	462	343	119	104	15
Total	1 597	1 240	356	280	77

Part B of Table 3-9 combines information from the AHS with total expenditure information to construct a "national" estimate of expenditures per housing unit measured in 1997 dollars. Note that the total of $1 597 maps back to the corresponding entry in Part B of Table 3-7. Reference to the table demonstrate that approximately three-quarters of all payments are to contractors and hired labor (i.e., $1 240 out of $1 597).

RECS — Residential Energy Consumption Survey

The 1997 RECS provides information on the use of energy in residential housing units in the United States. This information includes the physical characteristics of the housing units, the appliances utilized including space heating and cooling equipment, demographic characteristics of the household, the types of fuels used, and other information that relates to energy use. The 1997 RECS also provides energy consumption and expenditures data for natural gas, electricity, fuel oil, liquefied petroleum gas (LPG), and kerosene.

The RECS is a national statistical survey that collects energy-related data for occupied primary housing units. RECS was first conducted in 1978; the tenth survey was conducted in 1997. In the 1997 RECS, data were collected from a sample of 5 900 housing units statistically selected to represent the overall population of housing units in the United States.

Data for the 1997 RECS were obtained from three different sources: (1) on-site 30-minute personal interviews conducted in the housing unit; (2) telephone interviews with the rental agents of those rented housing units that have any of their energy use included in their rent; and (3) mail questionnaires mailed to the housing unit's energy suppliers asking them to provide the units' actual energy consumption amounts and expenditures.

Data from the 1997 RECS are available to the public in both printed[23] and electronic format. The electronic data are part of a set of public-use files available on DOE's RECS web-site.[24] The public-use files are used to produce the detailed classifications given in this report. However, each of the tables presented in this section is constructed so that readers can cross reference the column and row totals to values reported in the DOE document *A Look at Residential Energy Consumption in 1997.*

Three sets of data from the 1997 RECS are presented in Tables 3-10, 3-11, and 3-12. These tables record expenditures on a per housing unit basis. They help to visualize how the Nation's $135.8 billion expenditure for energy was distributed by tenure class, end use, and type of fuel. The three tables use the same type of housing units: single-family detached; single-family attached; multi-family, 2 to 4 units; multi-family, 5 or more units; and mobile home. This format was chosen to facilitate cross-referencing between individual entries in each of the three tables and between the three tables and the DOE document *A Look at Residential Energy Consumption in 1997.*

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[23] U.S. Department of Energy. 1999. *A Look at Residential Energy Consumption in 1997.* DOE/EIA-0632(97). Washington, DC: Energy Information Administration.

[24] http://www.eia.doe.gov/emeu/recs/

Table 3-10 records annual expenditures per housing unit for each type of housing unit and tenure class—owner-occupied, renter, and all units. It is important to recognize that the expenditures appearing under the "Owner-Occupied" and "Renter" headings in Table 3-10 are conditional on both the tenure class and the type of housing unit. Thus, the sums across each row or down each column do not add to the "total." This distinction may be better understood by recognizing that Table 3-10 also includes information on the percent of each type of housing unit that is occupied by owners and by renters. Reference to the "% of Type" heading reveals that multi-family dwellings are occupied primarily by renters. For example, owners account for 16.5 % of multi-family dwellings with 2 to 4 units and only 7.3 % of multi-family dwellings with 5 or more units. By and large, owner occupancies are highest in single-family dwellings and mobile homes.

Reference to the table reveals that the widest range of energy expenditures occurs in owner-occupied multi-family dwellings. Energy expenditures are highest in owner-occupied multi-family dwellings with 2 to 4 units—$1 650—and lowest in owner-occupied multi-family dwellings with 5 or more units—$736. Owner-occupied single-family detached and attached dwellings average $1 558 and $1 358, respectively. Expenditures for owner-occupied mobile homes averaged $1 219. With the exception of multi-family dwellings with 5 or more units, energy expenditures in renter-occupied dwellings were lower than comparable owner-occupied dwellings. For example, energy expenditures in renter-occupied single-family dwellings averaged about $225 less per housing unit. Energy expenditures for renter-occupied multi-family dwellings with 2 to 4 units were $650 less than comparable owner-occupied dwellings. When all housing units are considered (i.e., both owner-occupied and renter), the average annual expenditure for energy amounts to $1 338. It is important to recognize that the average across all units is an unconditional estimate.

Table 3-10. Energy Expenditures by Type of Housing Unit and Tenure Class: 1997

Type of Housing Unit	Tenure Class					
	Owner-Occupied		Rental		All Units	
	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit
Single-Family Detached	87.2	1 558	12.8	1 331	100.0	1 529
Single-Family Attached	55.0	1 358	45.0	1 131	100.0	1 256
Multi-Family, 2 to 4 units	16.5	1 650	83.5	1 001	100.0	1 108
Multi-Family, 5 or more units	7.3	736	92.7	757	100.0	755
Mobile Home	83.1	1 219	16.9	1 143	100.0	1 206
All Units	67.5	1 503	32.5	996	100.0	1 338

Note that the energy expenditure values recorded in the last column of Table 3-10 vary considerably as a function of the type of housing unit, with single-family detached dwellings the highest—$1 529—and multi-family dwellings with 5 or more units the lowest—$755. The same dollar values that appear under the "All Units" heading also appear under the "All End Uses" or "All Fuels" headings in Tables 3-11 and 3-12, respectively. These values are conditional only on the type of housing unit, whereas the values recorded in Table 3-10 under the "Owner-Occupied" or "Rental" headings are

conditional on the type of occupant. The distinction between conditional and unconditional values becomes more important as expenditures by end use and fuel type are examined. These values are recorded in Tables 3-11 and 3-12.

Table 3-11 records annual expenditures per housing unit for each type of housing unit and end use of energy. Five specific end uses of energy are recorded in the table. They appear under the headings of Space Heating, Air-Conditioning, Water Heating, Refrigerators, and Other Appliances (e.g., clothes dryers and cooking appliances) and Lighting. Note that with the exception of air-conditioning, almost all housing units employ each of the four remaining end uses of energy (i.e., the entries under the % of Type heading all exceed 96.5 %). Reference to the table reveals that other appliances and lighting are the single largest energy expenditure, accounting for more than one-third of all energy expenditures, followed by space heating, accounting for slightly less than one-third. The remaining one-third is associated with water heating, air-conditioning, and refrigerators. End use expenditures per housing unit across the various types of housing units show the greatest range for space heating—$336 (e.g., the difference between single-family detached dwellings and multi-family dwellings with 5 or more units)—and the least for water heating and refrigerators—a range of $40 and $42, respectively. The range of values for space heating reflects the fact that data on all climate zones are aggregated together. Thus, to the extent that certain types of housing units may be dominant in certain regions of the Nation, climatic variations will exert an influence on energy expenditures for space heating across housing types. The 1997 RECS public-use files permit this subject to be evaluated in detail.[25]

Table 3-12 records annual expenditures per housing unit for each type of housing unit and type of fuel. Five specific types of fuel are recorded in the table. They appear under the headings of Electricity, Natural Gas, Fuel Oil, Kerosene, and LPG. Note that electricity is the only fuel type used in all types of housing units. Expenditures for electricity account for approximately two-thirds of a housing unit's energy expenditures. Expenditures for the four remaining types of fuel are conditional, since many housing units do not use that fuel type. Of the four remaining types of fuel, natural gas is the most widely used; it is used in approximately 60 % of all housing units. Note that natural gas is not widely used in mobile homes (i.e., only 36.7 % of mobile homes use natural gas). Expenditures for natural gas range from $639 for single-family detached dwellings to $281 for multi-family dwellings with 5 or more units. The remaining fuel types—fuel oil, kerosene, and LPG—are used in less than 10 % of the Nation's housing units. However, the rates of use vary according to the type of housing unit. Note that LPG is used most extensively in mobile homes, where 27.0 % of all mobile homes use it. Because the expenditures for each fuel type tend to be conditional on the type of housing unit and the type of fuel, they can not be added to get the totals that appear under the headings of "All Units" and "All Fuels." However, the values recorded under the "% of Type" heading can be used as weights applied to the value under the "$/Unit" heading to "estimate" the values appearing in the "All Fuels" column for each type of housing unit.

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[25] Although detailed analyses of energy expenditures by Census region and climate zone are possible with the 1997 RECS public-use files, such analyses are considered beyond the purview of this report.

Summary of Key Statistics by Type of Expenditure

Since a great deal of information has been presented in this chapter, a summary table has been constructed to highlight some of the most significant expenditures data. Table 3-13 records this information. The table is divided into two parts. Part A records total expenditures in billions of 1997 dollars. Part B records annual expenditures per housing unit in 1997 dollars. Each part of Table 3-13 contains three columns. The first column identifies the statistic of interest. The second column records the dollar value of the statistic. The third column records the source of the information. In several cases, the values in the second column are estimated empirically. These values are noted with an "e" superscript in the first column and record more than one data source in the third column.

Table 3-11. Energy Expenditures by Type of Housing Unit and End Use: 1997

Type of Housing Unit	End Use											
	Space Heating		Air-Conditioning		Water Heating		Refrigerators		Other Appliances and Lighting		All End Uses	
	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit
Single-Family Detached	98.5	489	74.1	154	99.5	205	99.9	133	100.0	596	100.0	1 529
Single-Family Attached	99.4	439	66.2	116	99.9	187	100.0	111	100.0	445	100.0	1 256
Multi-Family, 2 to 4 units	99.8	436	60.9	85	99.8	173	100.0	102	100.0	347	100.0	1 108
Multi-Family, 5 or more units	96.7	153	68.9	98	98.1	165	99.5	91	100.0	288	100.0	755
Mobile Home	96.6	357	71.1	175	99.3	213	99.8	93	100.0	432	100.0	1 206
All Units	98.3	421	71.6	140	99.3	196	99.8	120	100.0	509	100.0	1 338

Table 3-12. Energy Expenditures by Type of Housing Unit and Type of Fuel: 1997

Type of Housing Unit	Type of Fuel											
	Electricity		Natural Gas		Fuel Oil		Kerosene		LPG		All Fuels	
	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit	% of Type	$/Unit
Single-Family Detached	100.0	985	63.2	639	10.6	809	4.0	117	9.5	518	100.0	1 529
Single-Family Attached	100.0	753	67.1	634	7.6	860	1.8	106	1.3	808	100.0	1 256
Multi-Family, 2 to 4 units	100.0	617	68.2	616	8.5	728	1.6	64	1.7	482	100.0	1 108
Multi-Family, 5 or more units	99.9	560	55.5	281	11.6	323	0.5	274	0.4	272	100.0	755
Mobile Home	100.0	899	36.7	438	1.8	374	9.2	270	27.0	423	100.0	1 206
All Units	100.0	871	61.0	579	9.8	714	3.4	144	8.0	500	100.0	1 338

Table 3-13. Summary of Key Statistics by Type of Expenditure

Part A: Expenditures in Billions of 1997 Dollars

Type of Expenditure	Dollar Value in Billions	Source
Value of Construction Put in Place: All Sectors	656.6	C30
Value of Construction Put in Place: Residential Sector	294.2	C30
Expenditures for Improvements	92.4	C50
Additions	14.6	C50
Alterations	37.1	C50
Outside Additions and Alterations	13.5	C50
Major Replacements	27.2	C50
Expenditures for Maintenance and Repair	41.1	C50
Expenditures for Energy	135.8	RECS

Part B: Average Annual Expenditures Per Housing Unit in 1997 Dollars

Type of Expenditure	Dollar Value	Source
Expenditures for Improvements[e]	888	C50 & AHS
Owner-Occupied[e]	1 106	C50 & AHS
Single-Family Dwelling[e]	1 135	C50 & AHS
Multi-Family Dwelling[e]	629	C50 & AHS
Rental[e]	589	C50 & AHS
Single-Family Dwelling[e]	897	C50 & AHS
Multi-Family, 2 to 4 Units[e]	256	C50 & AHS
Multi-Family, 5 Units or More[e]	430	C50 & AHS
Expenditures for Maintenance and Repair[e]	395	C50 & AHS
Owner-Occupied[e]	454	C50 & AHS
Single-Family Dwelling[e]	462	C50 & AHS
Multi-Family Dwelling[e]	325	C50 & AHS
Rental[e]	315	C50 & AHS
Single-Family Dwelling[e]	306	C50 & AHS
Multi-Family, 2 to 4 Units[e]	222	C50 & AHS
Multi-Family, 5 Units or More[e]	372	C50 & AHS
Expenditures for Energy: All Units	1 338	RECS
Tenure Class: All Units	1 338	RECS
Owner-Occupied	1 503	RECS
Rental	996	RECS
End Use: All End Uses	1 338	RECS
Space Heating	421	RECS
Air-Conditioning	140	RECS
Water Heating	196	RECS
Refrigerator	120	RECS
Other Appliances and Lighting	509	RECS
Type of Fuel: All Fuels	1 338	RECS
Electricity	871	RECS
Natural Gas	579	RECS
Fuel Oil	714	RECS
Kerosene	144	RECS
LPG	500	RECS

[e] Estimated

4. Service Life Measures

This chapter traces the development of the baseline measures of service life.[26] Data sources are described and matched to the key types of building elements (e.g., roofs, siding, and furnaces). The baseline measures of service life are then derived from the source data. The chapter concludes with a summary of the various baseline measures of service life.

4.1 Data Considerations: Sources, Availability, and Constraints

Preliminary data searches for the residential sector indicated that there were several sources of service life data. However, the data sources identified differed in terms of their focus, frequency of updating, and year of publication. Service life data from three sources are reported in this chapter. These data were all published within the last ten years; they are reported using a modified UNIFORMAT II[27] elemental classification. Two early studies on expected service lives for building elements are also included for reference purposes. The principal data sources that are used in this document are described below.

Data from the American Society for Testing and Materials

In 1996, the American Society for Testing and Materials (ASTM) formed Subcommittee E06.66 on Performance Standards for Dwellings. The goal of Subcommittee E06.66 is to produce a suite of standard guides for specifying and evaluating the performance of single-family attached and detached dwellings. Durability is one of 16 attributes against which performance is measured. The guides provide a framework for specifying and evaluating qualities of building products and systems to meet user needs without limiting ways and means. The format for the E06.66 suite of guides includes performance statements that consist of four components—Objective,[28] Criteria,[29] Evaluation,[30] and Commentary[31]—which together provide a systematic performance-based approach. Prior to approval by ASTM, each guide is balloted within Subcommittee E06.66 and subsequently by Committee E06 on Performance of Buildings. Comments by members of either the subcommittee or the full committee are incorporated into the document or set aside according to a rigorous consensus process.

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[26] The service life of a building component or material is defined as the period of time—measured in years—after installation during which all properties meet or exceed the minimum acceptable values when routinely maintained.

[27] American Society for Testing and Materials. 2001. *Standard Classification for Building Elements and Related Sitework—UNIFORMAT II.* E 1557. West Conshohocken, PA: American Society for Testing and Materials.

[28] A qualitative statement of the performance to be provided by the built element being addressed in order to satisfy a particular user need.

[29] Quantitative statements defining the level or range of performance necessary to meet an objective or, where such a level or range can not be established, the units of measurement of performance.

[30] The method(s) used to assess conformance of the built element being addressed to the criteria.

[31] An informative narrative explaining aspects of the performance statement.

The durability guide[32] was the first consensus performance standard to be published by Subcommittee E06.66. The durability guide provides examples of performance statements for durable in-place materials, products, components, subsystems, and systems for single-family attached and detached dwellings, considering the effects of normal degradation factors to which they are anticipated to be subjected over their service lives. The guide also includes a table with examples of minimum anticipated service lives of typical building elements. Because ASTM requires standards to be re-balloted at least every five years, the service life data reported in the durability guide can be updated to reflect advances in materials science and technology and new information from surveys and other empirical studies.

The hierarchy of building elements used in the suite of guides being produced by Subcommittee E06.66 differs slightly from the UNIFORMAT II elemental classification in that it includes at the top level of the hierarchy (i.e., level 1) an elemental grouping for the whole building system and for spaces (e.g., living spaces and dining spaces). In addition, the E06.66 hierarchy places greater emphasis on services (e.g., plumbing and HVAC) than does the UNIFORMAT II elemental classification. This is done by disaggregating services into their constituent elements and elevating the constituent elements to the top level of the hierarchy. This modified format is used in section 4.2, where specific values of service lives are reported. Key findings are summarized in section 4.3

Data from the National Association of Home Builders

The National Association of Home Builders (NAHB) is a federation of more than 800 state and local builders associations throughout the United States. Chief among NAHB's goals is providing and expanding opportunities for all consumers to have safe, decent, and affordable housing. Although the Nation's stock of housing continues to grow over time, the total housing stock contains a substantial proportion of older units. Therefore, durability-related issues have been and remain a major concern for NAHB.

Over the years, NAHB has published numerous articles and reports on durability-related issues. Among these publications is a *Housing Economics* article on service lives for housing components.[33] This article was based on a comprehensive survey of building materials manufacturers, trade associations, and researchers. The objective of the survey was to develop information on the longevity of housing components. Key findings from the survey are reported in section 4.2 and summarized in section 4.3.

More recently, NAHB has sponsored the National Family Opinion (NFO) Survey. As the NFO Survey reaches maturity, it will prove an excellent source of service life data, because the survey instrument contains a series of questions on housing type, floor space,

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[32] American Society for Testing and Materials. 2001. *Standard Guide for Specifying and Evaluating Performance of Single-Family Attached and Detached Dwellings—Durability*. E 2136. West Conshohocken, PA: American Society for Testing and Materials.

[33] Ahluwalia, Gopal, and Angela Shackford. 1993. "Life Expectancy of Housing Components." *Housing Economics* (August): pp. 5-9.

geographic location, types of exterior enclosure, and types of replacements. These questions will enable researchers at NIST and elsewhere to derive empirical estimates of service lives for key building elements based on well-defined subsets of the survey data. Furthermore, as the NFO Survey database grows, it will become possible to produce ranges of values for service lives. The survey instrument also includes questions on expenditures for housing improvements (e.g., additions, alterations, and major replacements). These data are currently under analysis and are planned for incorporation into a software product that NIST is developing for the PATH program. Unfortunately, due to data anomalies and questionnaire design issues, no results based on analysis of the NFO Survey data are included in this report.

Data from Whitestone Research

The *Whitestone Building Maintenance and Repair Cost Reference 1997* is the third of a series of annual reports produced by Whitestone Research[34] which presents estimates of 50 year maintenance cost profiles for 24 different building models. Example building types are elementary schools, fast food restaurants, motels, auto service garages, offices, supermarkets, and day care centers. These cover a good portion of the commercial/ institutional sector. The profile for each model includes a building description, a list of major building components, and forecasts of maintenance and repair costs at various levels of aggregation over the service life of the building. These costs can be adjusted for selected metropolitan areas, and modified to include different building components.

Although the Whitestone Reports focus on the types of buildings found in the commercial/institutional sector, the hierarchy of building elements contains many elements that are common to residential applications (e.g., roofing and siding). Since the Whitestone Reports contain information on the minimum anticipated service lives for a broad cross section of building elements, it is possible to select from that cross section only those building elements that are common to residential applications. The service lives of these "common" elements are reported in section 4.2. Key findings are summarized in section 4.3.

Other Data Sources

- American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE). ASHRAE has long recognized that equipment service life and maintenance cost data were required to perform life-cycle cost analyses. At the time of the first energy crisis, it became obvious that these data were not readily available and that confusion often existed with respect to their exact definition. Consequently, ASHRAE Technical Committee 1.8, Owning and Operating Costs, sponsored Research Project 186, Equipment Life and Maintenance Cost Survey. The results of this survey were published in the October 1978 issue of the *ASHRAE Journal*.[35] The

[34] Lufkin, Peter S., and Anthony J.Pepitone. 1997. *The Whitestone Building Maintenance and Repair Cost Reference 1997*. Seattle, WA: Whitestone Research.
[35] Akalin, Mustafat T. 1978. "Equipment Life and Maintenance Cost Survey." *ASHRAE Journal* (October): pp. 39-44.

equipment life and maintenance cost survey is noteworthy in that it provided not only expected values for equipment service lives but ranges of values that included the 25th percentile, the median (i.e., 50th percentile), the 75th percentile, and the mode (i.e., the most frequently observed value). Ranges of values for maintenance costs per unit of floor area were also provided for a variety of maintenance scenarios. The article also provided definitions for equipment elements and maintenance policies, which proved useful in subsequent studies.

- The California Energy Commission. Shortly after publication of the ASHRAE equipment life and maintenance cost survey, the California Energy Commission launched the 1980 Residential Building Standards Development Project. The goal of the project was to develop building standards which required new residential buildings to achieve the maximum possible energy savings while remaining cost-effective when compared with buildings built prior to 1975. Among the products of this project was a report establishing average service lives and maintenance costs for the major energy conserving and consuming components used in residential buildings.[36] These components included the building itself, space heating and air-conditioning systems, water heating systems, insulation, fans, pumps, and controls. The "Useful Lives" report is noteworthy in that it modified ASHRAE's list to focus on residential applications and included the service life of the building itself. This approach served to stimulate interest into how degradation of the building envelope (e.g., moisture penetration) affected residential energy conservation measures.

4.2 Baseline Measures of Service Life for Key Building Elements

The three tables presented in this section provide a detailed snapshot of service life data for typical building elements. Because service life data reported in the three tables come from different sources, there are differences both in data values and the elements reported. All three tables use the modified UNIFORMAT II elemental classification. Differences in data values stem from differences in focus (i.e., minimum service life versus average service life) and maintenance procedures (i.e., preventive versus reactive). Differences in building elements for which service life data are reported occur primarily at level 3—the most disaggregated and most detailed level of the elemental classification.

Table 4-1 presents service life data published in ASTM Standard Guide E 2136. These service life data are organized within a hierarchy that has ten level 1 elements. The ten level 1 elements are: (1) substructure; (2) shell; (3) interiors; (4) plumbing; (5) HVAC; (6) fire protection systems; (7) electrical network; (8) communication and security networks; (9) fuel networks; (10) fittings, furnishings, and equipment. Level 1 elements are disaggregated into level 2 elements. For example, the level 1 element shell is disaggregated into three level 2 elements: (1) superstructure; (2) exterior enclosure; and (3) roofing. Where appropriate, level 2 elements are disaggregated into level 3 elements. For example, the level 2 element roofing is disaggregated into two level 3 elements: (1) roof covering and (2) skylights.

[36] California Energy Commission. 1980. *Useful Lives and Maintenance Costs of Materials and Equipment.* Sacramento, CA: California Energy Commission.

Table 4-1. Examples of Minimum Anticipated Service Lives of Typical Building Elements: ASTM Standard Guide E 2136

Building Element			Minimum Anticipated Service Life Years
Substructure	Foundation		20 - 60
Shell	Superstructure		20 - 60
	Exterior Enclosure	Grade Enclosure	20 - 40
		Walls	20 - 40
		Wall finish - easily renewable	4 - 10
		Wall finish - difficult to renew	20 - 60
		Doors	20 - 25
		Windows	20 - 25
		Door and window finish - easily renewable	3 - 10
		Joint sealants	3 - 10
	Roofing	Roof covering	12 - 25
		Skylights	15 - 25
Interiors	Vertical Space Dividers	Partitions	20 - 40
		Partition surface finishes - easily renewable	3 - 10
		Partition surface finishes - difficult to renew	15 - 25
		Doors	15 - 35
		Doors - easily renewable door paint	3 - 10
	Horizontal Space Dividers	Floor surfaces - bath and w.c.	4 - 20
		Floor surfaces - other	3 - 20
		Ceiling surfaces - private spaces: easily renewable	3 - 10
		Ceiling surfaces - private spaces: difficult to renew	15 - 25
	Stairs and Ramps	Stair surfaces - private spaces	3 - 15
Plumbing	Piping	Accessible	15 - 30
		Inaccessible	20 - 40
	Fixtures		15 - 25
	Fixture Trim		5 - 15
	Hot Water Heater		5 - 15
HVAC	Fuel Pump		10 - 15
	Pipes	Accessible	10 - 20
		Inaccessible	20 - 40
	Radiators		15 - 40

Table 4-1. Examples of Minimum Anticipated Service Lives of Typical Building Elements: ASTM Standard Guide E 2136 (continued)

Building Element			Minimum Anticipated Service Life Years
HVAC	Fan Coil Units		15 - 20
	Pumps		10 - 15
	Boilers		10 - 20
	Mechanical Refrigerator	Machines	15 - 20
	Evaporative Coolers		8 - 15
	Furnaces		15 - 20
	Duct Work	Accessible	20 - 40
		Inaccessible	20 - 25
	Louvers		5 - 40
	Thermostats		5 - 15
	Exhaust Fans		5 - 15
Fire Protection Subsystems			5 - 30
Electrical Network	Conductors	Accessible	20 - 25
		Inaccessible	20 - 40
	Conduit		20 - 40
	Exposed Raceways		15 - 40
	Switches		5 - 15
	Sockets		5 - 15
	Overcurrent Protection	Circuit breaker	5 - 20
	Panels		20 - 40
	Switch Board		20 - 40
	Light Fixtures		5 - 15
Communication and Security Networks	Television Antenna		5 - 20
Fuel Networks	Fuel Storage	Above ground	10 - 20
		Below ground	20 - 30
	Fuel Supply Piping	Accessible	20 - 30
		Inaccessible	20 - 40
Fittings, Furnishings and Equipment	Furnishings	Built-in furnishings	5 - 20
		Built-in furnishings surfaces - easily renewable	5 - 10

The service life data reported in Table 4-1 differ from the service life data reported in Tables 4-2 and 4-3. The reason for the difference is that the service life data reported in Table 4-1 are the "minimum" anticipated service lives for the building elements identified. The service life data reported in Tables 4-2 and 4-3 are "average" anticipated service lives for the building elements identified. Thus, one would expect that the minimum anticipated service life for a particular building element would be strictly less than the average anticipated service life for that same building element. Both the minimum anticipated service life and the average anticipated service life are useful in choosing among alternative investments.[37] Use of a preventive maintenance program could also affect both the minimum anticipated service life and the average anticipated service life of a particular building element. Because the focus of the Whitestone Reports is primarily on the commercial/institutional sector, there is a stronger emphasis on the use of a preventive maintenance program than in most residential applications. Thus, although both Tables 4-2 and 4-3 report average anticipated service lives, the values in Table 4-3 reflect the use of a formal maintenance program.

Because ASTM Standard Guide E 2136 was intended for use as a guidance document in specifying minimum performance requirements, Table 4-1 reports minimum anticipated service lives. Providers (e.g., homebuilders or special trade contractors) in preparing their responses are free to propose alternatives that meet or exceed the minimum performance requirements. Note that the values in Table 4-1 are ranges and not single point estimates. Ranges of values are needed for two reasons. First, if an item (i.e., single building element) is drawn (i.e., sampled) from a population of "identical" items and observed, then the time until that item/building element is no longer serviceable results in a specific value. If many "identical" building elements are sampled and their specific values are recorded, what results is a distribution of values with some measure of central tendency and two tails—a lower tail resulting in sooner replacement and an upper tail resulting in prolonged use. Specifying the minimum anticipated service life, focuses on characterizing key parameters associated with the lower tail of this "empirical" distribution and developing estimates for them (e.g., the first percentile). Estimating the values of these parameters from empirical data involves uncertainty. For example, a different sample will probably result in a different estimated value for the first percentile. Thus a range of values results. Second, there is often considerable performance variation within a given level 3 building element. For example, roof coverings include a wide range of products (e.g., shingles, tile, slate, and sheet metal) each of which has a minimum anticipated service life. Thus, a range of values is needed to capture performance variation within a given building element.[38]

Reference to Table 4-1 shows that the level 3 elements associated with the superstructure and shell have the highest minimum anticipated service lives. This is especially true for

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[37] ASTM Standard Guide E 2156 provides several examples of how to use service life data to assist in choosing among alternative investments, see American Society for Testing and Materials. 2001. *Standard Guide for Evaluating Economic Performance of Alternative Designs, Systems, and Materials in Compliance with Performance Standard Guides for Single-Family Attached and Detached Dwellings*. E 2156. West Conshohocken, PA: American Society for Testing and Materials.

[38] The same statement holds if we are concerned about average anticipated service life.

such critical elements as the foundation and superstructure both of which have minimum anticipated service life ranges of 20 years to 60 years. Exterior enclosure and roofing elements have minimum anticipated service lives that tend to correlate with the ease of replacement (i.e., low values for easily renewable exterior finishes and joint sealants and high values for grade enclosures, walls, and difficult to renew exterior finishes). For level 3 elements under interiors, the minimum anticipated service lives tend to correlate with their ease of replacement. For example, partitions and partition and ceiling surfaces that are difficult to renew have minimum anticipated service life ranges of 20 years to 40 years, 15 years to 25 years, and 15 years to 25 years, respectively. Easily renewable surfaces have ranges of 3 years to 10 years. Services (e.g., plumbing, HVAC, electrical networks, and fuel networks) have many critical elements that are difficult to renew. These elements tend to have minimum anticipated service life ranges of 20 years to 40 years.

Table 4-2 reports service life data extracted from a 1993 article in *Housing Economics*.[39] These data are based on the average anticipated service life for a wide variety of building elements. For many building elements, a range of values for the average anticipated service life is given. Several building elements have very high values for their average anticipated service lives. For example, the average anticipated service life for poured footings and foundations is 200 years and when brick and stone walls are used as exterior enclosures their average anticipated service life exceeds 100 years.[40] Many building elements have "Lifetime" recorded under the average anticipated service life column heading. The term lifetime is used to denote the life expectancy of the housing unit (i.e., the average useful life of the unit). Although a specific value for "Lifetime" was not reported in the article, other studies have reported values for the "average" life expectancy of a housing unit between 45 years and 60 years.[41] The three level 3 elements of the housing unit's substructure/foundation all have average anticipated service lives of 50 years or more. The level 3 elements associated with the housing unit's shell tend to be correlated with the ease of replacement. For example, the basement floor system, framing for exterior walls, and chimneys have "Lifetime" recorded under the average anticipated service life column heading. Note that Table 4-2 provides service life data on several key types of siding and roof coverings. For siding, average anticipated service lives for wood, steel, aluminum, and vinyl are reported. For roof coverings, average anticipated service lives for asphalt and wood shingles and shakes, tile, slate, and sheet metal are reported. Turning to the level 3 elements associated with interiors, we see average anticipated service lives of between 5 years and 10 years for finishes (e.g., paint, trim, and wallpaper), between 30 years and "Lifetime" for doors,[42] and considerable variation for floor coverings. For example, the average anticipated service life for carpet is 11 years, for vinyl sheet or tile, 20 years to 30 years, and "Lifetime" for oak, pine, marble, slate flagstone, and terrazzo.

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[39] Ahluwalia and Shackford, "Life Expectancy of Housing Components."

[40] When the average anticipated service life for a specific building element exceeds the stated value, a plus sign "+" is used. Thus, 100+ indicates that the average anticipated service life for brick and stone walls exceeds 100 years.

[41] California Energy Commission, *Useful Lives and Maintenance Costs of Materials and Equipment.*

[42] The level 3 element doors-not perfect hollow core has a range for average anticipated service life of less than 30 years to "Lifetime." This range is designated as: < 30 – Lifetime.

Table 4-2. Examples of Average Anticipated Service Lives of Typical Building Elements: Housing Economics

Building Element			Average Anticipated Service Life Years
Substructure	Foundation	Poured footings and foundations	200
		Concrete block	100
		Cement	50
Shell	Superstructure		Lifetime
	Exterior Enclosure	Basement floor system	Lifetime
		Framing (exterior walls)	Lifetime
		Exterior paint on wood, brick and aluminum	7 - 10
		Gutters and downspouts	30
		Siding - wood	10 - 100
		Siding - metal (steel)	50 - Lifetime
		Siding - aluminum	20 - 50
		Siding - vinyl	50
		Exterior door (protected overhang)	80 - 100
		Exterior door (unprotected and exposed)	25 - 30
		Screen door	25 - 50
		Garage doors	20 - 50
		Window glazing	20
		Windows - wood casement	20 - 50
		Windows - aluminum casement	10 - 20
		Window screen	25 - 50
		Chimney	Lifetime
		Brick and stone walls	100+
	Roofing	Roof covering - asphalt and wood shingles and shakes	15 - 30
		Roof covering - tile	50
		Roof covering - slate	50 - 100
		Roof covering - sheet metal	20 - 50+
		Built-up roofing - asphalt	12 - 25
		Built-up roofing - coal and tar	12 - 30
		Asphalt composition shingle	15 - 30
		Asphalt overlag	25 - 35
Interiors	Vertical Space Dividers	Walls - drywall and plaster	30 - 70
		Walls - ceramic tile	Lifetime

Table 4-2. Examples of Average Anticipated Service Lives of Typical Building Elements: Housing Economics (continued)

Building Element			Average Anticipated Service Life Years
Interiors	Vertical Space Dividers	Framing (interior walls)	Lifetime
		Doors - not perfect hollow core	< 30 - Lifetime
		Doors - solid corewood	30 - Lifetime
		Folding door	30 - Lifetime
		Interior wall paint	5 - 10
		Interior trim and door	5 - 10
		Wallpaper	7
	Horizontal Space Dividers	Floor surfaces - vinyl sheet or vinyl tile	20 - 30
		Floor surfaces - oak or pine	Lifetime
		Floor surfaces - marble	Lifetime
		Floor surfaces - slate flagstone	Lifetime
		Floor surfaces - terrazzo	Lifetime
		Carpeting	11
		Ceiling suspension	Lifetime
		Acoustical ceiling	Lifetime
	Masonry	Fireplace and brick veneer	Lifetime
		Stucco and mantels	Lifetime
	Stairs and Ramps	Stairs	50 - 100
		Rails and disappearing stairs	30 - 40
Plumbing	Waste pipe	Concrete	50 - 100
		Cast iron	75 - 100
	Sinks	Enamel steel sinks	5 - 10
		Enamel cast iron sinks	25 - 30
		China sinks	25 - 30
	Faucets	Low quality	13 - 15
		High quality	15 - 20
	Water Heater	Gas	11 - 13
		Electric	14
HVAC	Air Conditioning Unit	Central unit	15
		Window unit	10
	Air Conditioning Compressor		15
	Humidifier		8

Table 4-2. Examples of Average Anticipated Service Lives of Typical Building Elements: Housing Economics (continued)

Building Element			Average Anticipated Service Life Years
HVAC	Duct Work	Plastic	15
		Galvanized	30
	Rooftop Air Conditioners		15
	Boilers, Hot Water (Steam)		30
	Furnaces	Gas or oil fired	18
		Heat pumps	15
	Unit Heaters	Gas or Electric	13
	Radiant Heaters	Electric	10
		Hot water or steam	25
	Air Terminals	Diffusers, grilles, and registers	27
	Induction and Fan-Coil Units		20
	Dampers		20
	Fans	Centrifugal	25
		Axial	20
		Ventilating roof-mounted	20
	Coils	DX, water, or steam	20
		Electric	15
	Heat Exchangers	Shell-and-tube	24
	Molded Insulation Molded		20
	Pumps, Sump and Well		10
	Burners		21
Fire Protection Subsystems	Smoke Detectors		12
	Smoke/Fire/Intrusion Systems		10
Electrical Network	Copper Wiring	Copper plated	100+
		Copper clad aluminum	100+
		Bare copper	100+
	Insulation	Armored cable (BX)	Lifetime
		Conduit	Lifetime

Table 4-3. Examples of Average Anticipated Service Lives of Typical Building Elements: Whitestone

Building Element			Average Anticipated Service Life Years
Shell	Exterior Enclosure	Solid core (painted) exterior door	40
		Refinish solid core (painted) exterior door	4
		Aluminum siding, 1st floor	80
		Refinish aluminum siding, 1st floor	5
	Roofing	Replace new over existing asphalt shingle roof	20
		Removal and replacement of asphalt shingle roof	40
Interiors	Vertical Space Dividers	Hollow core (painted) interior door	30
		Refinish hollow core (painted) interior door	4
		Fabric interior wall finish	10
	Horizontal Space Dividers	Vinyl tile flooring	18
		Acoustic tile ceiling	70
	Stairs and Ramps	Refinish masonry interior steps (painted)	6
Plumbing	Fixtures	Sink - stainless steel	40
		Valve set, sink, stainless steel	10
		Hot water storage tank	50
		New gasket, pipe and fittings, cast iron	50
		Pipe and fittings, cast iron	75
		Pump and motor assembly, sump pump	20
		Compressed air dryer	15
HVAC	Fuel Supply Systems	Fuel oil pump	15
	Heat Generation Systems	Gas house furnace	15
	Heat Rejection Systems	Chiller, reciprocal air cooled hermetic	20
	Heat Distribution Systems	Air handler, singlezone	15
	Heat Transfer	Air conditioner, indoor DX packaged, air cooled	20
Fire Protection Subsystems	Fire Protection Sprinkler Systems	Fire sprinkler head	20
Electrical Network	Electrical Service and Distribution	Transformer, dry, less than 15 000 V	30
	Lighting and Branch Wiring	Fluorescent lighting fixture, 160 W	20
	Communication and Security Systems	Fire alarm control panel	15
	Special Electrical System	Generator, 1000 kW diesel	25

The remaining elements in Table 4-2 are all associated with services (i.e., plumbing, HVAC, fire protection subsystems, and the electrical network). Note that ranges of values are reported for elements under the plumbing heading, whereas the other services report point estimates. For example, enamel cast iron sinks have an average anticipated service life range of 25 years to 30 years, whereas a central air conditioning unit has a point estimate of 15 years. As was observed earlier, an element's average anticipated service life tends to be correlated with its ease of replacement. For example, replacement of the electrical network is a significant undertaking. Reference to Table 4-2 shows that all elements under the electrical network heading have average anticipated service lives of either "Lifetime" or 100+.

Table 4-3 presents service life data from Whitestone Research.[43] These data are all presented as point estimates. It is also important to note that the average anticipated service life data from Whitestone assume that a formal maintenance program is in place. This is because Whitestone's focus is primarily on commercial/institutional applications. Service life data from Whitestone cover the housing unit's shell, interiors, and services (i.e., plumbing, HVAC, fire protection subsystems, and the electrical network). The Whitestone data also include a number of durability-related activities, such as refinishing, replacement over an existing element, and removal and replacement. For example, refinishing activities occur on a cycle that ranges from 4 years to 6 years. In the case of roofing, the replacement of new asphalt shingles over an existing asphalt shingle roof is expected to have an average anticipated service life of 20 years. If the old shingles are removed and replaced with new asphalt shingles, then the average anticipated service life is 40 years.

4.3 Summary of Baseline Measures of Service Life

This section summarizes the baseline measures of service life presented in Section 4.2. These measures are presented in Table 4-4.

The table is organized to serve as a quick reference; it includes a brief description of each measure, the value of the measure, and the source of the service life data. The entries in Table 4-4 are organized according to the national expenditure patterns for major replacements presented in Table 3-8 in section 3.3. The key expenditure patterns that are drawn from Table 3-8 and presented in Table 4-4 cover building elements associated with plumbing, HVAC, siding, roofing, windows, and doors. Elements of the key expenditure patterns are organized under a heading (e.g., plumbing). Each heading is denoted through the use of a bold font (e.g., **Plumbing**). Individual building elements under a heading are indented and grouped according to their function (e.g., water heaters). This grouping facilitates comparisons between the three source documents. For example, according to ASTM Standard Guide E 2136, the minimum anticipated service life for hot water heaters ranged from 5 years to 15 years. Average anticipated service lives reported by *Housing Economics* and Whitestone were 11 years to 13 years for gas water heaters, 14 years for electric water heaters, and 50 years for hot water storage tanks, respectively.

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[43] Lufkin and Pepitone, *The Whitestone Building and Maintenance and Repair Cost Reference 1997.*

Table 4-4. Summary of Baseline Measures of Service Life

Building Element	Service Life in Years	Source
Plumbing		
Fixtures	15 - 25	ASTM E 2136
Enamel steel sinks	5 - 10	Housing Economics
Enamel cast iron sinks	25 - 30	Housing Economics
China sinks	25 - 30	Housing Economics
Stainless steel sinks	40	Whitestone
Low quality faucets	13 - 15	Housing Economics
High quality faucets	15 - 20	Housing Economics
Hot water heater	5 - 15	ASTM E 2136
Gas water heater	11 - 13	Housing Economics
Electric water heater	14	Housing Economics
Hot water storage tank	50	Whitestone
HVAC		
Evaporative coolers	8 - 15	ASTM E 2136
Central air conditioning unit	15	Housing Economics
Window air conditioning unit	10	Housing Economics
Air conditioner, indoor DX packaged, air cooled	20	Whitestone
Furnaces	15 - 20	ASTM E 2136
Gas or oil fired furnaces	18	Housing Economics
Gas house furnaces	15	Whitestone
Heat pumps	15	Housing Economics
Siding		
Wall finish - easily renewable	4 - 10	ASTM E 2136
Wall finish - difficult to renew	20 - 60	ASTM E 2136
Siding - wood	10 - 100	Housing Economics
Siding - metal (steel)	50 - Lifetime	Housing Economics
Siding - aluminum	20 - 50	Housing Economics
Siding - vinyl	50	Housing Economics
Aluminum siding, 1st floor	80	Whitestone

Table 4-4. Summary of Baseline Measures of Service Life (continued)

Building Element	Service Life in Years	Source
Roofing		
Roof covering	12 - 25	ASTM E 2136
Roof covering - asphalt and wood shingles and shakes	15 - 30	Housing Economics
Roof covering - tile	50	Housing Economics
Roof covering - slate	50 - 100	Housing Economics
Roof covering - sheet metal	20 - 50+	Housing Economics
Replace new over existing asphalt shingle roof	20	Whitestone
Removal and replacement of asphalt shingle roof	40	Whitestone
Windows		
Windows	20 - 25	ASTM E 2136
Windows - wood casement	20 - 50	Housing Economics
Windows - aluminum casement	10 - 20	Housing Economics
Doors		
Doors	20 - 25	ASTM E 2136
Exterior doors (protected overhang)	80 - 100	Housing Economics
Exterior doors (unprotected and exposed)	25 - 30	Housing Economics
Solid core (painted) exterior doors	40	Whitestone

Groupings under the headings of Siding and Roofing also provide interesting comparisons. ASTM Standard Guide E 2136 reports service life data on exterior wall finishes. Siding is included primarily under difficult to renew finishes but also, to a lesser extent, under easily renewable finishes. The resultant ranges of minimum anticipated service lives are 20 years to 60 years and 4 years to 10 years, respectively. Low-end average anticipated service life values from *Housing Economics* range from 10 years for wood to 50 years for metal (steel). High-end average anticipated service lives all exceed 50 years. Whitestone reports a single value of 80 years for aluminum siding. In the case of Roofing, ASTM Standard Guide E 2136 reports a range of minimum anticipated service life values between 12 years and 25 years. Average anticipated service life values from *Housing Economics* range from 15 years to 30 years for asphalt and wood shingles and shakes to 50 years to 100 years for slate. Whitestone reports two types of roofing service life data, one for replacement with new shingles over existing shingles of 20 years, and one for removal of the old shingles and replacement with new shingles of 40 years. Similar comparisons can be made for HVAC, Window, and Door elements.

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5. Durability-Related Cost Measures

This chapter traces the development of baseline measures of durability-related costs. Data sources are described and matched to the key types of durability-related costs (e.g., replacements of roofs and siding, or maintenance and repair expenditures). The baseline measures of durability-related costs are then derived from the source data. The chapter concludes with a summary of the various baseline measures of durability-related costs.

5.1 Data Considerations for Durability-Related Cost Measures

Data searches for the residential sector indicated that there were two main sources of durability-related cost measures. These sources are the American Housing Survey and the Residential Energy Consumption Survey. These data sources are described below.

Data from the American Housing Survey (AHS)

Since AHS was introduced and described briefly in chapter 3, the focus here is on how the AHS data were used to develop selected sets of baseline measures for durability-related costs. The material presented in this chapter is drawn from the 1997 AHS. The 1997 AHS data are available as a set of public-access files. These files permit the data tabulated in the published report[44] to be "sliced and diced" in a variety of ways. Data dimensions analyzed and presented in this chapter include key building elements (e.g., siding) associated with three major durability-related cost categories (i.e., major replacements, maintenance and repair, and alterations), the type of housing unit (i.e., all units or single-family detached units), who did the work (i.e., contractor or household), and the floor area of the unit. These data dimensions, when analyzed and summarized, provide a fairly detailed snapshot of a wide variety of durability-related costs. Note that the AHS cost data are "conditional," since they include only those cases where an expenditure was made to perform a specific function (e.g., siding replacement). Conditional cost data are used to capture the fact that many durability-related expenditures do not occur on an annual basis. An approach for "smoothing" out such expenditure patterns is outlined in section 6.2.

Data from the Residential Energy Consumption Survey (RECS)

Since the RECS was introduced and described briefly in chapter 3, the focus here is on how the RECS data were combined with information from the AHS to develop selected sets of baseline measures of "estimated" energy expenditures per unit of floor area. Data from the 1997 RECS are available to the public in both printed[45] and electronic format. The electronic data are part of a set of public-use files available on DOE's RECS web-site. The public-use files are used to produce the detailed classifications given in section

[44] U.S. Department of Housing and Urban Development. 1999. *American Housing Survey for the United States: Current Housing Reports*. H150/97. Washington, DC: Office of Policy Development and Research.
[45] U.S. Department of Energy. 1999. *A Look at Residential Energy Consumption in 1997*. DOE/EIA-0632(97). Washington, DC: Energy Information Administration.

5.2.4 of this report. The baseline measures of energy expenditures per unit of floor area are estimates because the RECS does not collect data on the actual floor area of the housing units surveyed. The RECS does ask respondents to indicate which of seven size categories their housing unit falls into. The RECS size categories are specified in conventional units; they range from less than 600 ft^2 to 3 000 ft^2 (55.7 m^2 to 278.7 m^2) or more.[46] The seven RECS size categories are less than 600 ft^2 (55.7 m^2), 600 ft^2 to 999 ft^2 (55.7 m^2 to 92.8 m^2), 1 000 ft^2 to 1 599 ft^2 (92.9 m^2 to 148.6 m^2), 1 600 ft^2 to 1 999 ft^2 (148.6 m^2 to 185.7 m^2), 2 000 ft^2 to 2 399 ft^2 (185.8 m^2 to 222.9 m^2), 2 400 ft^2 to 2 999 ft^2 (223.0 m^2 to 278.6 m^2), and 3 000 ft^2 (278.7 m^2) or more. Since the size of the housing units in RECS is given as a range for the unit's floor area, it was necessary to develop estimated values for the floor area of the units within each RECS size category. Since the AHS data files contain values for each surveyed unit's floor area, they were used to "estimate" the median size for each RECS size category. The median unit sizes corresponding with each of the seven RECS size categories are 400 ft^2 (37.2 m^2), 836 ft^2 (77.7 m^2), 1 272 ft^2 (118.2 m^2), 1 800 ft^2 (167.2 m^2), 2 144 ft^2 (199.2 m^2), 2 600 ft^2 (241.5 m^2), and 3 600 ft^2 (334.5 m^2). These median sizes were used to estimate the energy expenditures per ft^2 (m^2).

Other Data Sources

- The National Family Opinion (NFO) Survey is a nationwide survey sponsored by the National Association of Home Builders. As the NFO Survey reaches maturity, it will prove an excellent source of durability-related cost data, because the survey instrument contains a series of questions on housing type, floor space, geographic location, types of exterior enclosure, and types of replacements. These questions will enable researchers at NIST and elsewhere to derive empirical estimates of durability-related costs (e.g., additions, alterations, and major replacements) for key building elements based on well-defined subsets of the survey data. Furthermore, as the NFO Survey database grows, it will become possible to produce ranges of values for durability-related costs. These data are currently under analysis and are planned for incorporation into a software product that NIST is developing for the PATH program. Unfortunately, due to data anomalies and questionnaire design issues, no results based on analysis of the NFO Survey data are included in this report.

- The R. S. Means Company, Inc., produces annual sets of cost information on a wide variety of building types for use by owners, developers, architects, engineers, contractors, and others to project and control the costs of both new building construction and renovation projects. The Means Repair & Remodeling Cost Data[47] book is intended for use by builders doing small-scale remodeling jobs as well as building managers needing costs and time estimates for building

[46] Values of floor space expressed in square feet are denoted by ft^2. Values of floor space expressed in square meters are denoted by m^2.

[47] R. S. Means Company, Inc. 2002. *Means Repair & Remodeling Cost Data.* 23rd edition. Kingston, MA: R. S. Means Company, Inc.

renovations. The Means Repair & Remodeling Cost Data book contains information on both commercial and residential renovation projects.

5.2 Baseline Measures of Durability-Related Costs: Major Replacements, Maintenance and Repair, Alterations, and Energy

The material presented in this section is organized around paired sets of figures and tables. With the exception of Tables 5-13, 5-19, and 5-29, which are of a summary nature, and Tables 5-30 through 5-32, which deal with energy expenditures, all tables have the same format. This tabular format is designed to complement the graphical information displayed on the figure which is paired with that table. For example, Figure 5-1 and Table 5-1 are paired.

The vertical axis of each figure (i.e., Figures 5-1 through 5-26) records the cost per household for the building element under analysis (e.g., roof replacements). The horizontal axis records information on the size of the housing units, as measured by the six size categories used in the AHS. The AHS size categories are specified in customary units. The six AHS size categories are less than 500 ft^2 (46.5 m^2), 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2), 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2), 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2), 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2), and 2 500 ft^2 (232.3 m^2) or more. An aggregated total category is also displayed on each figure; this size category is labeled "all sizes." Note that size categories used in the AHS differ from those used in the RECS. A range of durability-related cost data is reported on each figure. The values are constructed so that they cover the inter-quartile range (i.e., the middle 50 % of the overall distribution) of costs reported in the AHS for that building element and housing unit size category for the selected data dimensions analyzed (e.g., type of cost, type of housing unit, and who did the work). Four statistical measures are plotted on each figure: (1) the 75th percentile, represented by a square (■); (2) the mean, represented by a diamond (◆); (3) the median, represented by a triangle (▲); and the 25th percentile, represented by an x (×). If insufficient data are available (i.e., less than 20 observations) to report the inter-quartile range for a specific size category, then only the mean value is reported for that size category. If there are less than five (5) observations in a specific size category, then no value is reported for that size category.

The tables are constructed so that each of the values plotted on the corresponding figure is recorded in one of the four subheadings under the "Cost per Household" heading. The four subheadings correspond to the four statistical measures (i.e., 25th percentile, median, 75th percentile, and mean). The leftmost column of each table records the size of the housing unit in ft^2 (m^2). All tables use the same size categories that are used in the figures.

Each paired figure/table combination is presented on a page by itself. This method of display was selected to facilitate comparisons between graphical and tabular results.

5.2.1 Major Replacements

Major replacements involve the replacement of an entire system (e.g., replacement of the entire roof). Major replacements also cover substitutions (e.g., substitution of a new bathtub for an old one). Major replacements tend to be high cost items (e.g., replacements of roofs and siding). However, there are a number of items that are relatively low in cost (e.g., garbage disposals) that when replaced are considered to be major replacements.

Figure 5-1 and Table 5-1 show the cost per household for replacing a roof over the entire home for all owner occupied units where a contractor did the work. Since less than 20 observations are available for the smallest size category, only the mean is reported for that size category. Reference to Table 5-1 shows that the mean cost per household increases from $1 524 for a unit size of less than 500 ft^2 (46.5 m^2) to $4 962 for a unit size of 2 500 ft^2 (232.3 m^2) or more. This is an increase of more than three times. The 75th percentile displays a similar pattern. The cost per household increases from $2 700 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) to $5 700 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The cost per household for all sizes for the 75th percentile is $4 500 and the mean cost per household is $3 667.

Figure 5-2 and Table 5-2 show the cost per household for replacing a roof over the entire home for owner occupied single-family detached units where a contractor did the work. Since less than five observations are available for the smallest size category, no value is reported for that size category. Notice that the costs are not much higher than for replacing the roof over the entire home for all owner occupied units where a contractor did the work (see Figure 5-1 and Table 5-1), since owner occupied single-family detached housing makes up the largest portion of the residential sector. The mean cost per household increases from $2 294 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) to $4 962 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $3 743. For all sizes, the 25th percentile shows a cost per household of $1 800, the median shows a cost per household of $2 800, and the 75th percentile shows a cost per household of $4 500.

Figure 5-3 and Table 5-3 show the cost per household for replacing a roof over the entire home for all owner occupied units where the household did the work. Since less than five observations are available for the smallest size category, no value is reported for that size category. Reference to Table 5-3 shows that the mean cost per household exhibits an interesting pattern; it first increases from $1 254 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) to $1 901 for a unit size of 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2). The mean cost per household then decreases to $1 790 for a unit size of 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2) and then increases to $2 402 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $1 829. A similar pattern results for the median cost per household. The median cost per household for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) is $1 000 and increases to $1 500 for a unit size of 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2). The median cost per household then decreases to $1 200 for a unit size of 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2) and

then increases to \$2 000 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The median cost per household for all sizes is \$1 300. Note that these costs are significantly lower than where a contractor did the roof replacement (compare Figure 5-3 and Table 5-3 with Figure 5-1 and Table 5-1).

Figure 5-1. Major Replacement of a Roof Over Entire Home (All Owner Occupied Units – Contractor Did the Work)

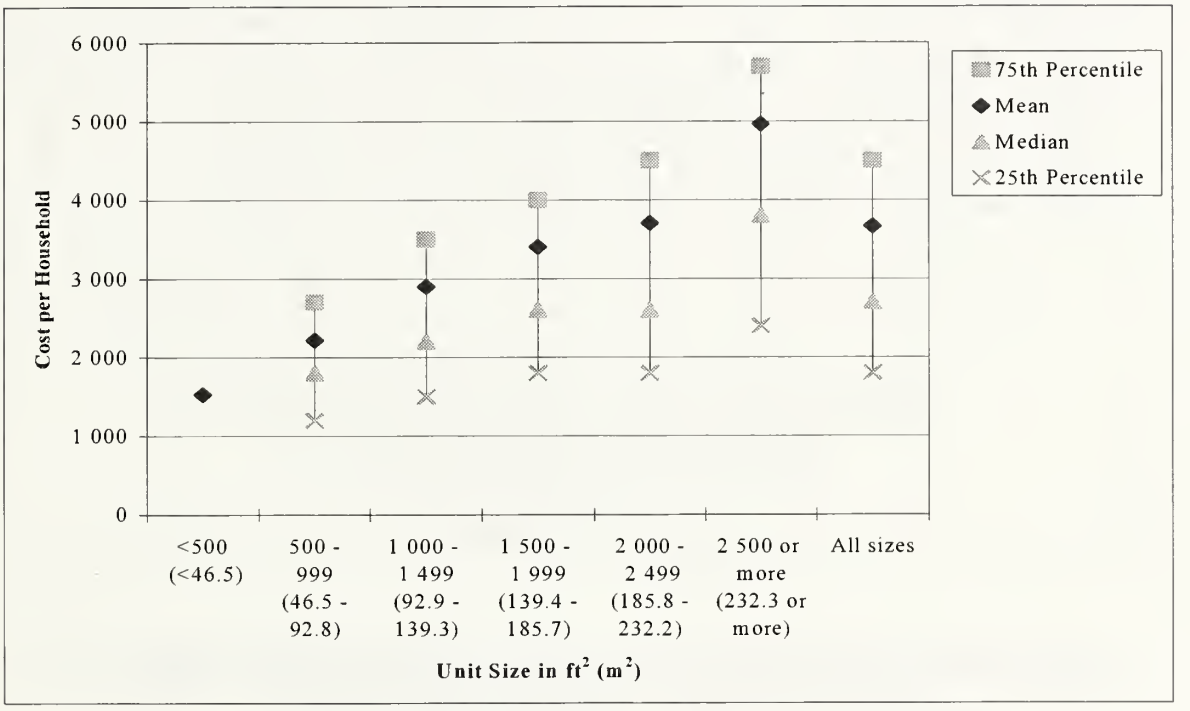

Table 5-1. Major Replacement of a Roof Over Entire Home (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	1 524
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	1 200	1 800	2 700	2 217
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	1 500	2 200	3 500	2 896
1 500 ft^2 to 1 999 ft^2 (139.4m^2 to 185.7 m^2)	1 800	2 600	4 000	3 403
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	1 800	2 600	4 500	3 705
2 500 ft^2 or more (232.3 m^2 or more)	2 400	3 800	5 700	4 962
All sizes	1 800	2 700	4 500	3 667

Figure 5-2. Major Replacement of a Roof Over Entire Home (Owner Occupied Single-Family Detached - Contractor Did the Work)

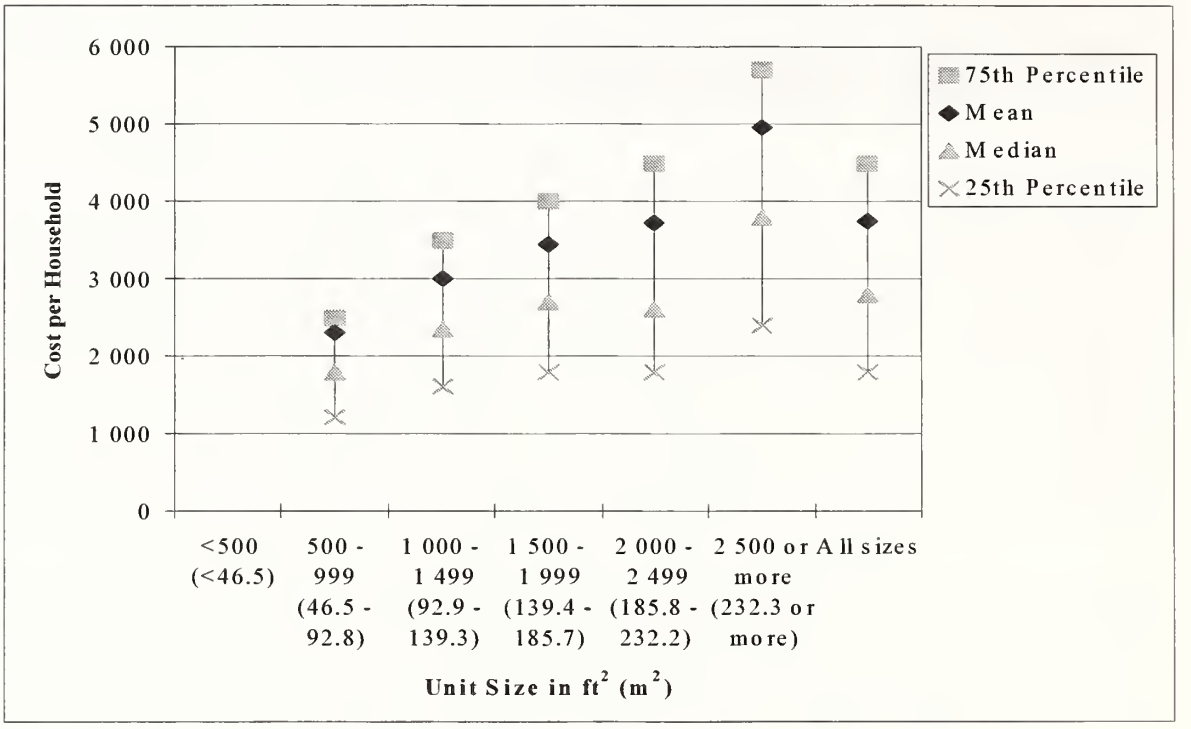

Table 5-2. Major Replacement of a Roof Over Entire Home (Owner Occupied Single-Family Detached - Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	1 200	1 800	2 500	2 294
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	1 600	2 342	3 500	2 997
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	1 800	2 700	4 000	3 435
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	1 800	2 600	4 500	3 715
2 500 ft^2 or more (232.3 m^2 or more)	2 400	3 800	5 700	4 962
All sizes	1 800	2 800	4 500	3 743

Figure 5-3. Major Replacement of a Roof Over Entire Home (All Owner Occupied Units – Household Did the Work)

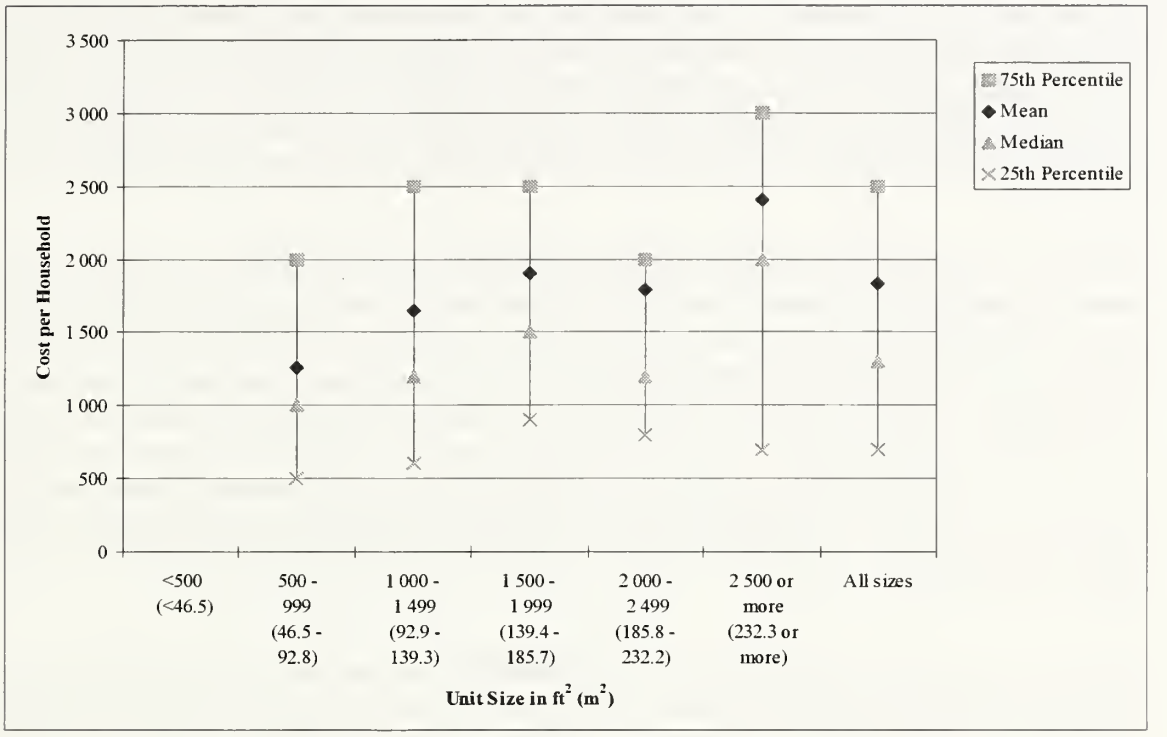

Table 5-3. Major Replacement of a Roof Over Entire Home (All Owner Occupied Units – Household Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	500	1 000	2 000	1 254
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	600	1 200	2 500	1 645
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	900	1 500	2 500	1 901
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	800	1 200	2 000	1 790
2 500 ft^2 or more (232.3 m^2 or more)	700	2 000	3 000	2 402
All sizes	700	1 300	2 500	1 829

Figure 5-4 and Table 5-4 show the cost per household for replacing a roof over the entire home for owner occupied single-family detached units where the household did the work. The cost per household for all size units is $800 for the 25th percentile and increases to $2 500 for the 75th percentile. The mean cost per household for all sizes is $1 873. The mean cost per household for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) is $1 381 and increases to $2 430 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household is slightly lower (i.e., $1 807 versus $1 867) for a unit size of 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2) than for a unit size of 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2).

Figure 5-5 and Table 5-5 show the cost per household to replace doors or windows for all owner occupied units where a contractor did the work. The cost per household for all sizes is $300 for the 25th percentile and increases to $2 550 for the 75th percentile. The mean cost per household for all sizes is $2 012. The costs per household for the largest size category (2 500 ft^2 (232.3 m^2) or more) are less than the costs per household for the 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2) size category. Note the extreme variability in costs for the 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2) size category, where the 75th percentile is $4 000. The median cost per household remains constant at $800 for the three size categories of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) through 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2).

Figure 5-6 and Table 5-6 show the cost per household for replacing doors or windows for owner occupied single-family detached units where a contractor did the work. The mean cost per household follows an interesting pattern. It first decreases from $1 921 for the 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) size category to $1 589 for the 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) size category and then increases to $2 810 for a unit size of 2 000 ft^2 to 2 400 ft^2 (185.8 m^2 to 232.2 m^2). The mean cost of replacing doors and windows for the largest size category (2 500 ft^2 (232.3 m^2) or more) is $2 126, a difference of nearly $700 from the 2 000 ft^2 to 2 400 ft^2 (185.8 m^2 to 232.2 m^2) size category. The mean cost for all sizes is $2 108. The median cost per household is $825 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $1 435 for a unit size of 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2). Notice the lowest costs are shown for unit sizes of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2). The median cost per household for all sizes is $1 000.

The median cost per household for replacing doors or windows for all owner occupied units where the household did the work is $200 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and $300 for a unit size of 2 500 ft^2 (232.3 m^2) or more (i.e., a $100 increase in the cost as is shown in Figure 5-7 and Table 5-7). The range for the cost per household is even less for the 25th percentile. The cost per household starts at $70 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $150 for a unit size of 2 500 ft^2 (232.3 m^2) or more for a range of $80. The mean cost per household is $329 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $775 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $590.

Figure 5-4. Major Replacement of a Roof Over Entire Home (Owner Occupied Single-Family Detached - Household Did the Work)

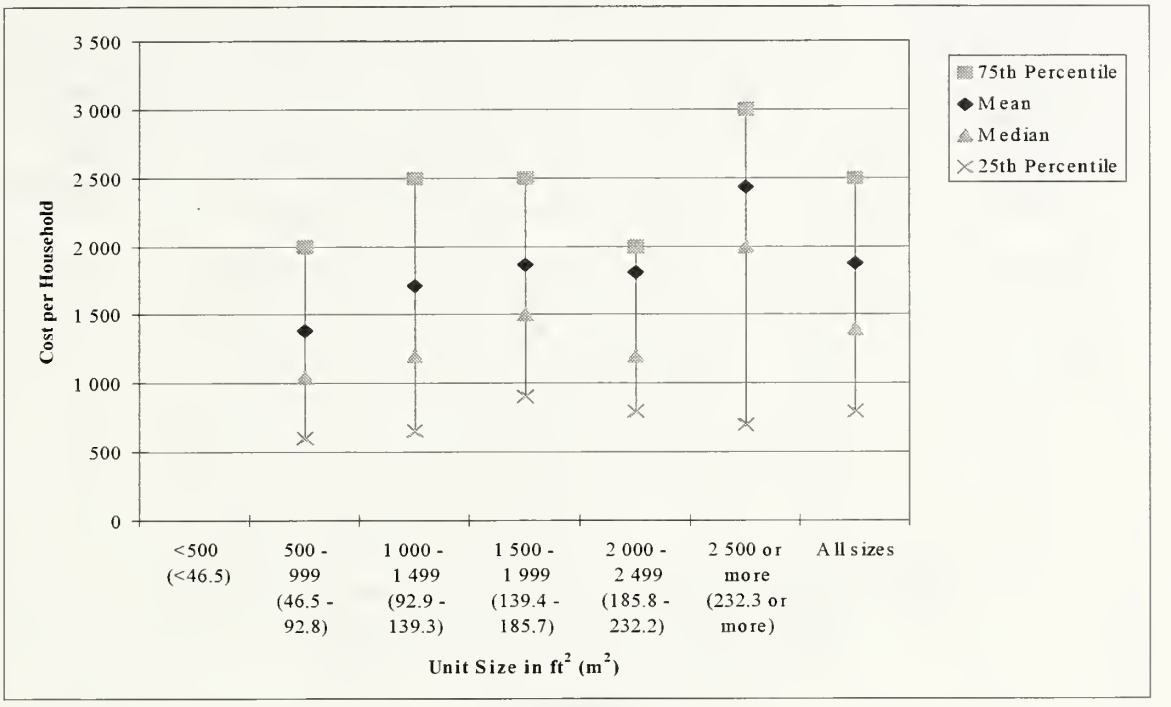

Table 5-4. Major Replacement of a Roof Over Entire Home (Owner Occupied Single-Family Detached - Household Did the Work)

Unit Size in ft² (m²)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft² (Less than 46.5 m²)	-	-	-	-
500 ft² to 999 ft² (46.5 m² to 92.8 m²)	600	1 050	2 000	1 381
1 000 ft² to 1 499 ft² (92.9 m² to 139.3 m²)	650	1 200	2 500	1 710
1 500 ft² to 1 999 ft² (139.4 m² to 185.7 m²)	900	1 500	2 500	1 867
2 000 ft² to 2 499 ft² (185.8 m² to 232.2 m²)	800	1 200	2 000	1 807
2 500 ft² or more (232.3 m² or more)	700	2 000	3 000	2 430
All sizes	800	1 400	2 500	1 873

Figure 5-5. Major Replacement of Doors or Windows (All Owner Occupied Units – Contractor Did the Work)

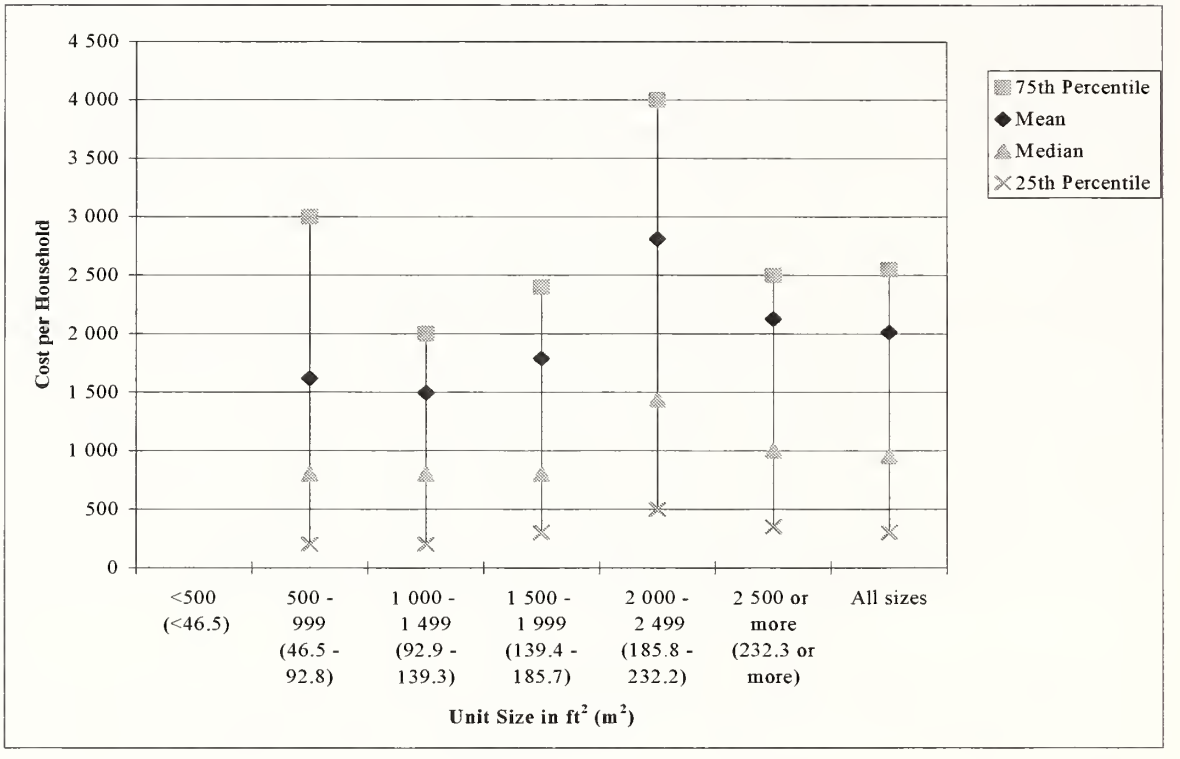

Table 5-5. Major Replacement of Doors or Windows (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	200	800	3 000	1 619
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	200	800	2 000	1 496
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	300	800	2 400	1 789
2 000 ft^2 to 2,499 ft^2 (185.8 m^2 to 232.2 m^2)	500	1 435	4 000	2 810
2 500 ft^2 or more (232.3 m^2 or more)	350	1 000	2 500	2 126
All sizes	300	951	2 550	2 012

Figure 5-6. Major Replacement of Doors or Windows (Owner Occupied Single-Family Detached – Contractor Did the Work)

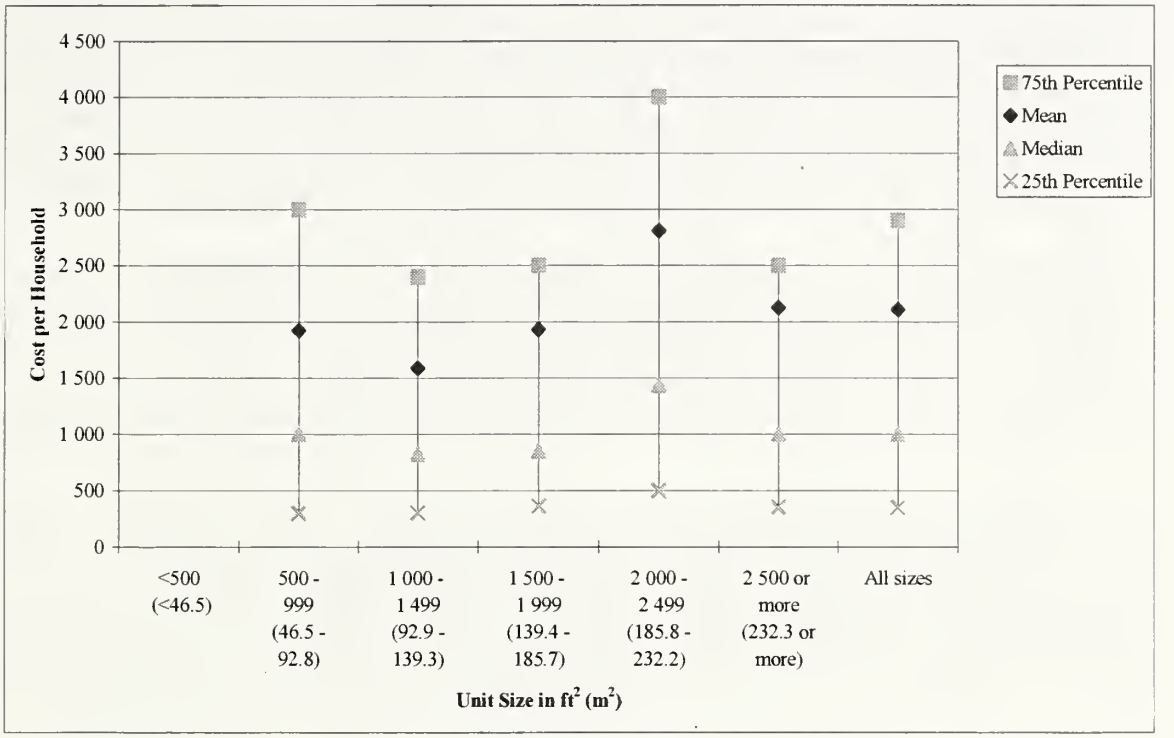

Table 5-6. Major Replacement of Doors or Windows (Owner Occupied Single-Family Detached – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	300	1 000	3 000	1 921
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	300	825	2 400	1 589
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	360	850	2 500	1 929
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	500	1 435	4 000	2 810
2 500 ft^2 or more (232.3 m^2 or more)	350	1 000	2 500	2 126
All sizes	350	1 000	2 900	2 108

Figure 5-7. Major Replacement of Doors or Windows (All Owner Occupied Units – Household Did the Work)

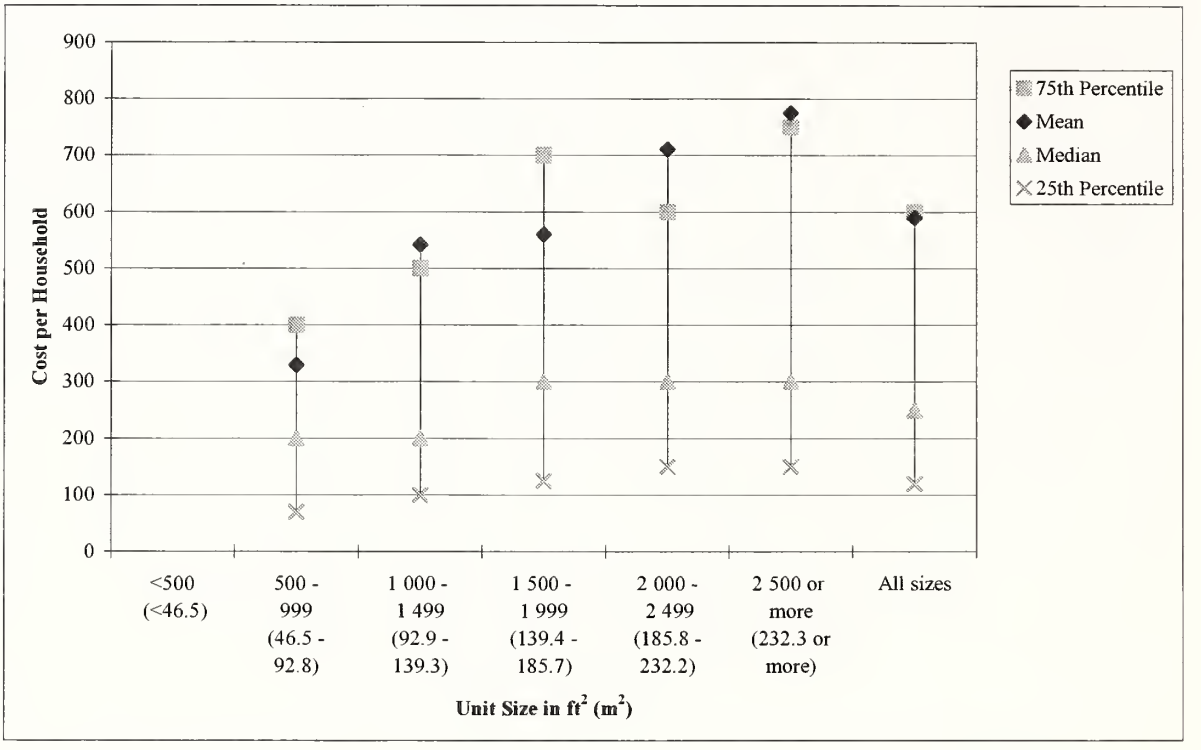

Table 5-7. Major Replacement of Doors or Windows (All Owner Occupied Units – Household Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	70	200	400	329
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	100	200	500	542
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	125	300	700	560
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	150	300	600	711
2 500 ft^2 or more (232.3 m^2 or more)	150	300	750	775
All sizes	120	250	600	590

Figure 5-8 and Table 5-8 show the cost per household to replace doors or windows for owner occupied single-family detached units where the household did the work. The mean cost starts at $376 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $778 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all size units is $628. The median cost per household starts at $200 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $300 for a unit size of 2 500 ft^2 (232.3 m^2) or more. Notice that the median cost per household remains constant at $300 for a unit size of 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2) up to a unit size of 2 500 ft^2 (232.3 m^2) or more. The median cost per household for all sizes is $300.

The major replacement of all siding for all owner occupied units by a contractor is shown in Figure 5-9 and Table 5-9. The mean cost per household starts at $3 970 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $7 284 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $6 433. The cost per household for all sizes is $3 000 for the 25th percentile, $5 419 for the median, and $8 900 for the 75th percentile.

Figure 5-10 and Table 5-10 show the cost per household to replace all siding for all owner occupied units where the household did the work. The mean cost per household is $1 983 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $4 024 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $2 935. The cost per household is $1 000 for the 25th percentile, $2 000 for the median, and $3 000 for the 75th percentile.

Figure 5-11 and Table 5-11 show the cost per household to replace the furnace, heat pump, or boiler and maintenance and repair of furnace/heating equipment parts for all owner occupied units where a contractor did the work. Note that maintenance and repair costs are included in the cost data presented in Figure 5-11 and Table 5-11. This is due to a data extraction problem in the AHS public-access files.[48] The mean cost is $890 for a unit size of less than 500 ft^2 (46.5 m^2) and increases to $2 346 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost for all sizes is $2 058. The cost per household for all sizes is $1 000 for the 25th percentile, $1 800 for the median, and $2 700 for the 75th percentile.

Figure 5-12 and Table 5-12 show the cost per household for replacing the central air conditioning by a contractor for all owner occupied units. The mean cost per household is $2 051 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $3 072 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) is $2 473. The mean cost per household decreases slightly to $2 437 for the 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2) size category. The mean cost per household for all sizes is $2 624. The 75th percentile shows a cost per household of $3 000 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2); it increases to $4 000 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The

[48] The Census Bureau has been informed of the unintentional commingling of expenditures for maintenance and repair with major replacements for this data element.

cost per household for all sizes for the 75th percentile is $3 500. The median cost per household for all sizes is $2 400.

Figure 5-8. Major Replacement of Doors or Windows (Owner Occupied Single-Family Detached – Household Did the Work)

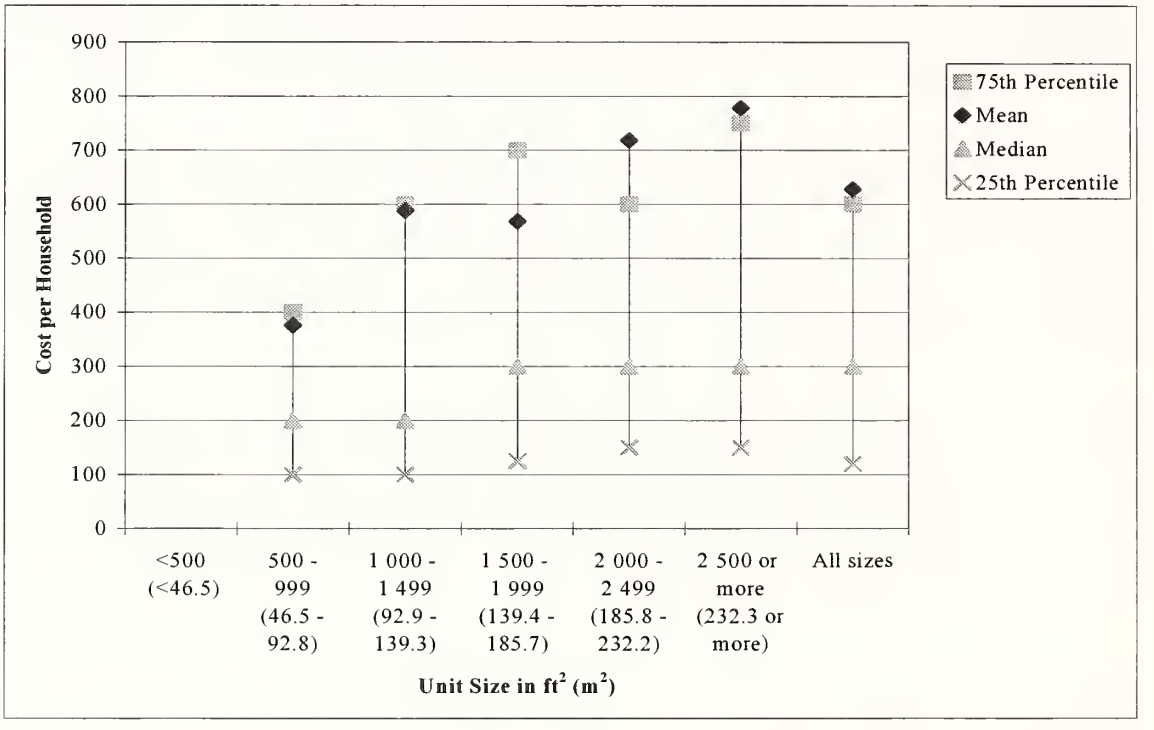

Table 5-8. Major Replacement of Doors or Windows (Owner Occupied Single-Family Detached – Household Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	100	200	400	376
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	100	200	600	588
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	125	300	700	568
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	150	300	600	718
2 500 ft^2 or more (232.3 m^2 or more)	150	300	750	778
All sizes	120	300	600	628

Figure 5-9. Major Replacement of All Siding (All Owner Occupied Units – Contractor Did the Work)

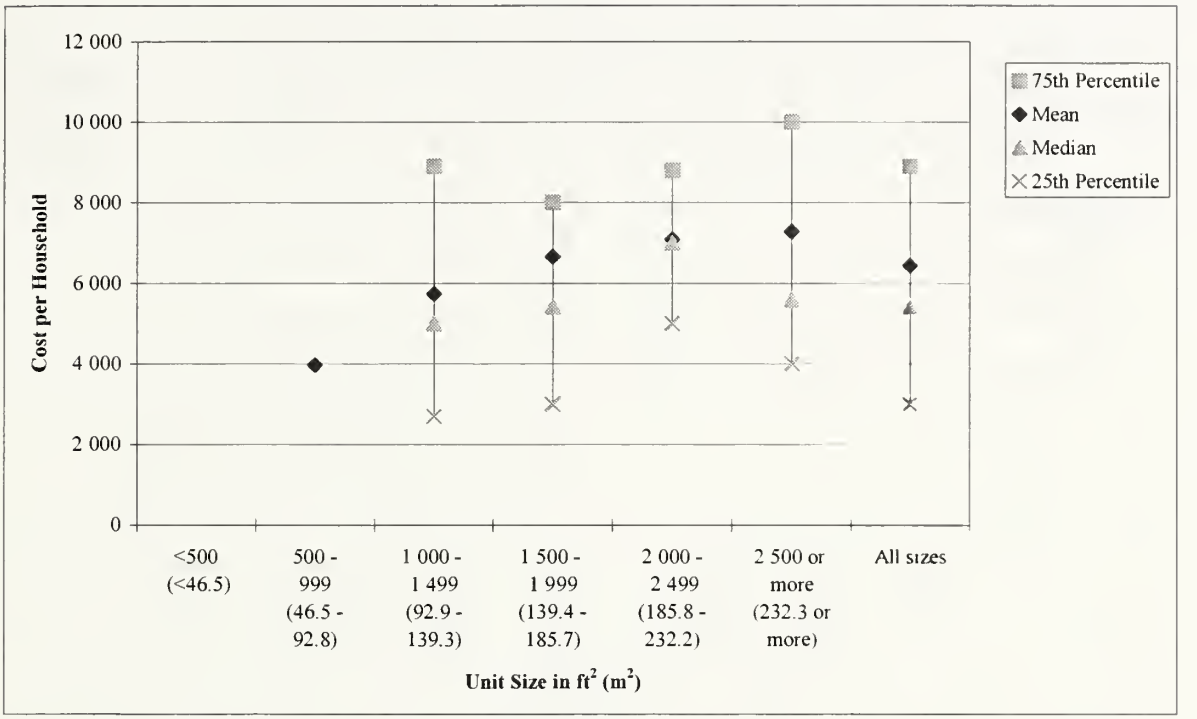

Table 5-9. Major Replacement of All Siding (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft² (m²)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft² (Less than 46.5 m²)	-	-	-	-
500 ft² to 999 ft² (46.5 m² to 92.8 m²)	-	-	-	3 970
1 000 ft² to 1 499 ft² (92.9 m² to 139.3 m²)	2 686	5 000	8 900	5 738
1 500 ft² to 1 999 ft² (139.4 m² to 185.7 m²)	3 000	5 419	8 000	6 658
2 000 ft² to 2 499 ft² (185.8 m² to 232.2 m²)	5 000	7 000	8 800	7 086
2 500 ft² or more (232.3 m² or more)	4 000	5 600	10 000	7 284
All sizes	3 000	5 419	8 900	6 433

Figure 5-10. Major Replacement of All Siding (All Owner Occupied Units – Household Did the Work)

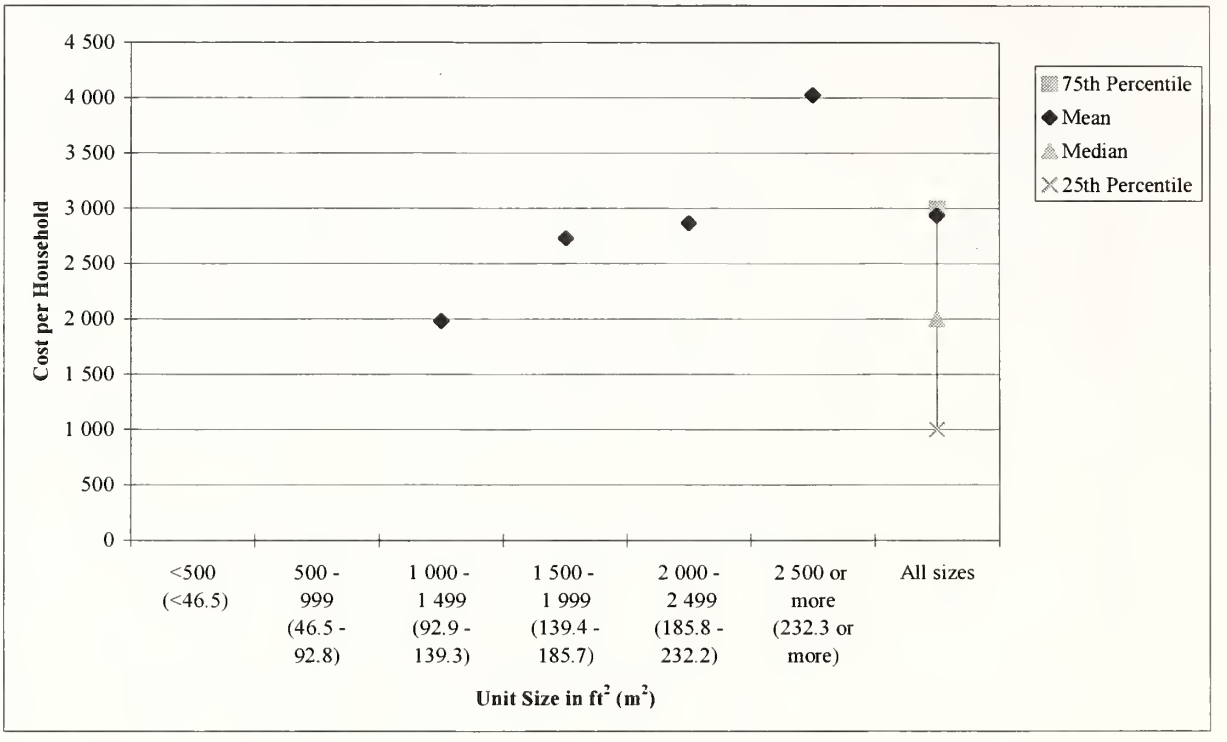

Table 5-10. Major Replacement of All Siding (All Owner Occupied Units – Household Did the Work)

Unit Size in $ft^2(m^2)$	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	-
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	-	-	-	1 983
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	-	-	-	2 731
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	-	-	-	2 867
2 500 ft^2 or more (232.3 m^2 or more)	-	-	-	4 024
All sizes	1 000	2 000	3 000	2 935

Figure 5-11. Major Replacement of Furnace, Heat Pump, or Boiler and Maintenance and Repair of Furnace/Heating Equipment Parts (All Owner Occupied Units – Contractor Did the Work)

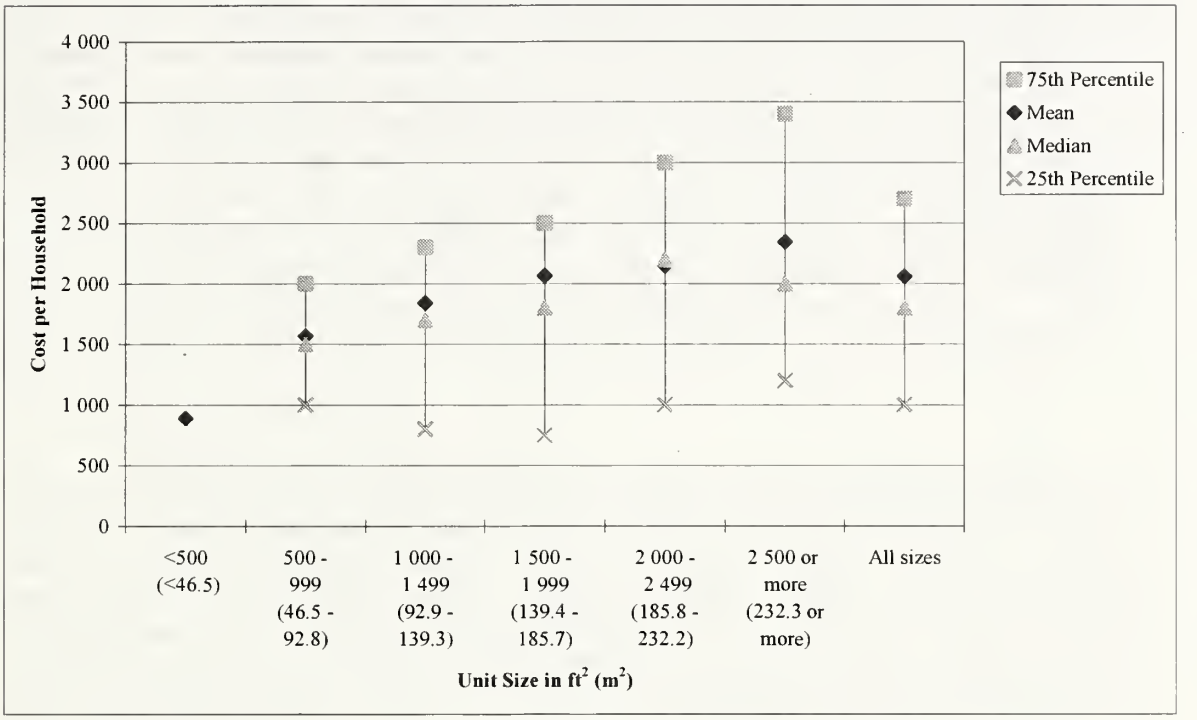

Table 5-11. Major Replacement of Furnace, Heat Pump, or Boiler and Maintenance and Repair of Furnace/Heating Equipment Parts (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	890
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	1 000	1 500	2 000	1 568
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	800	1 700	2 300	1 841
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	750	1 800	2 500	2 065
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	1 000	2 200	3 000	2 147
2 500 ft^2 or more (232.3 m^2 or more)	1 200	2 000	3 400	2 346
All sizes	1 000	1 800	2 700	2 058

Figure 5-12. Major Replacement of Central Air Conditioning (All Owner Occupied Units – Contractor Did the Work)

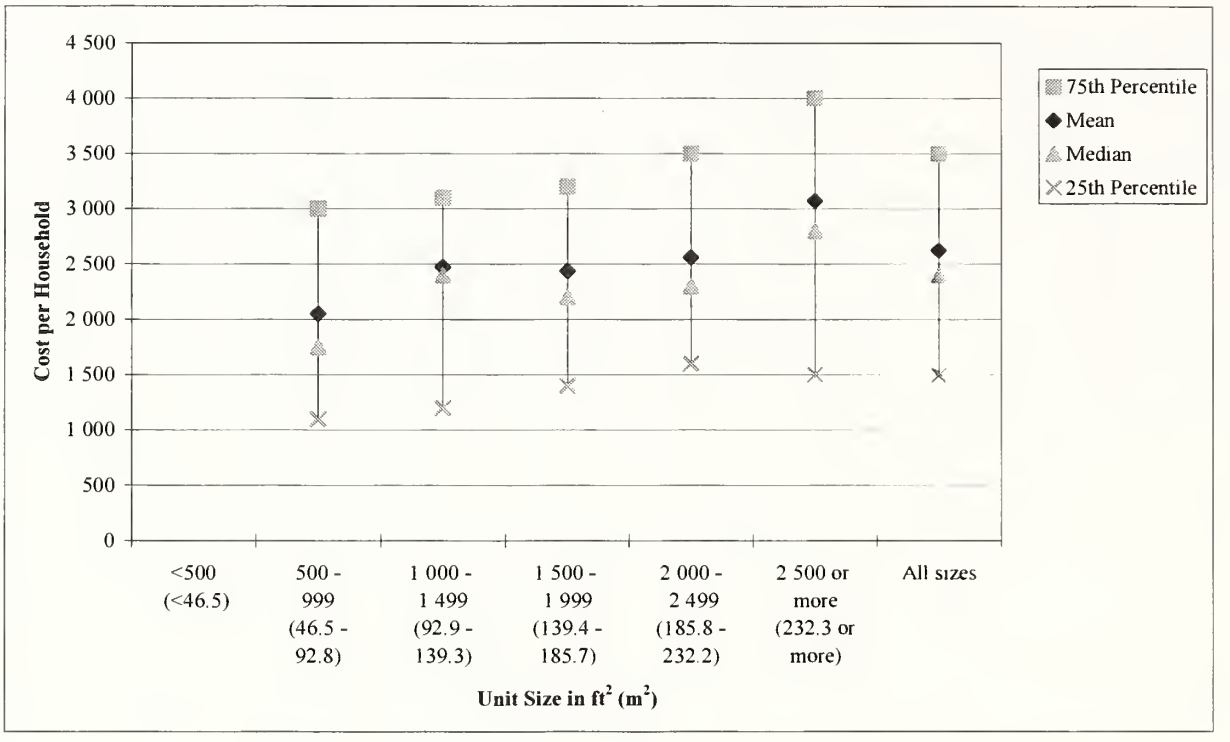

Table 5-12. Major Replacement of Central Air Conditioning (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft² (m²)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft² (Less than 46.5 m²)	-	-	-	-
500 ft² to 999 ft² (46.5 m² to 92.8 m²)	1 100	1 750	3 000	2 051
1 000 ft² to 1 499 ft² (92.9 m² to 139.3 m²)	1 200	2 400	3 100	2 473
1 500 ft² to 1 999 ft² (139.4 m² to 185.7 m²)	1 400	2 200	3 200	2 437
2 000 ft² to 2 499 ft² (185.8 m² to 232.2 m²)	1 600	2 300	3 500	2 561
2 500 ft² or more (232.3 m² or more)	1 500	2 800	4 000	3 072
All sizes	1 500	2 400	3 500	2 624

Table 5-13 shows the designation and selected major replacement costs of building elements by statistical measure. The designation column shows a two-letter code. A code of AC represents all owner occupied units with a contractor doing the work, AH represents all owner occupied units with the household doing the work, SC represents owner occupied single-family detached units with a contractor doing the work, and SH represents owner occupied single-family detached units with the household doing the work. The four statistical measures are recorded under the "Cost per Household" heading. Looking at the water heater building element, the lowest mean cost per household is $236. This represents the cost for all owner occupied units with the household doing the work. The highest mean cost per household is $416 and this is represented by owner occupied single-family detached units with a contractor doing the work. Note that the costs of homeowner replacements of the water heater in all units are about the same as in single-family detached units (e.g., $236 versus $241). A similar pattern results if the water heater is replaced by a contractor (i.e., $408 versus $416).

5.2.2 Maintenance and Repair

Maintenance and repair expenditures represent current costs for incidental maintenance and repair activities that keep a property in ordinary working condition, rather than an additional investment in the property. Maintenance includes such expenses as painting, papering, floor sanding, and furnace cleaning or adjustment. Repairs include many kinds of expenditures for plumbing, heating, electrical work, and other kinds of activity involved in the upkeep of residential properties. Repairs also include replacements of parts and of whole units, except for a select list specified below that are classified as major replacements.[49]

Figure 5-13 and Table 5-14 show the cost per household for maintenance and repairs to finished flooring for all owner occupied units with a contractor doing the work. The median cost per household for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) is $376 and increases to $1 500 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household starts at $610 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $2 290 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The 25^{th} percentile for all sizes shows a cost per household of $400. The 75^{th} percentile for all sizes shows a cost per household of $2 000. The mean cost per household is $1 626.

Figure 5-14 and Table 5-15 show the cost per household for maintenance and repairs to finished flooring for all owner occupied units with the household doing the work. The mean cost per household doubles from $423 for a unit size less than 500 ft^2 (46.5 m^2) to $852 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost for all sizes is $643. The cost per household for all sizes for the 25^{th} percentile is $100 and increases to $600 for the 75^{th} percentile.

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[49] The following is a list of items that, when replaced, are considered to be major replacements as opposed to repairs: complete furnace or boiler, entire roof, central air-conditioning, all siding, water heater, entire electrical wiring, doors, plumbing fixtures, all water pipes, windows, septic tank or cesspool, sink or laundry tub, complete walks or drive ways, and garbage disposal unit.

Table 5-13. Selected Major Replacement of Building Elements by Designation and the Cost per Household

Building Element	Designation	Cost per Household			
		25th Percentile	Median	75th Percentile	Mean
All siding	SC	3 000	5 419	8 900	6 454
All siding	SH	1 000	2 200	3 000	3 039
Furnace, heat pump, or boiler and maintenance and repair of furnace/heating equipment parts	AH	200	800	1 600	1 115
Central air conditioning	SC	1 500	2 400	3 500	2 622
Central air conditioning	AH	800	2 000	3 400	2 252
Central air conditioning	SH	1 000	2 000	3 500	2 476
Water heater	AC	200	325	500	408
Water heater	AH	150	200	300	236
Water heater	SC	200	325	500	416
Water heater	SH	150	200	300	241
Plumbing fixtures	AC	110	250	500	694
Plumbing fixtures	AH	60	100	210	223
Plumbing fixtures	SC	120	250	500	714
Plumbing fixtures	SH	60	100	225	230
Interior water pipes	AC	175	800	2 000	1 340
Interior water pipes	AH	50	275	600	401
Electrical wiring	AC	500	800	1 820	1 479
Electrical wiring	AH	150	300	500	442
Septic tank	AC	1 300	2 000	3 200	2 580
Septic tank	AH	-	-	-	1 587
Dishwasher	AC	350	410	500	457
Dishwasher	AH	300	400	500	389
Garbage disposal	AC	100	140	200	151
Garbage disposal	AH	57	80	110	94

Figure 5-13. Maintenance and Repairs to Finished Flooring (All Owner Occupied Units – Contractor Did the Work)

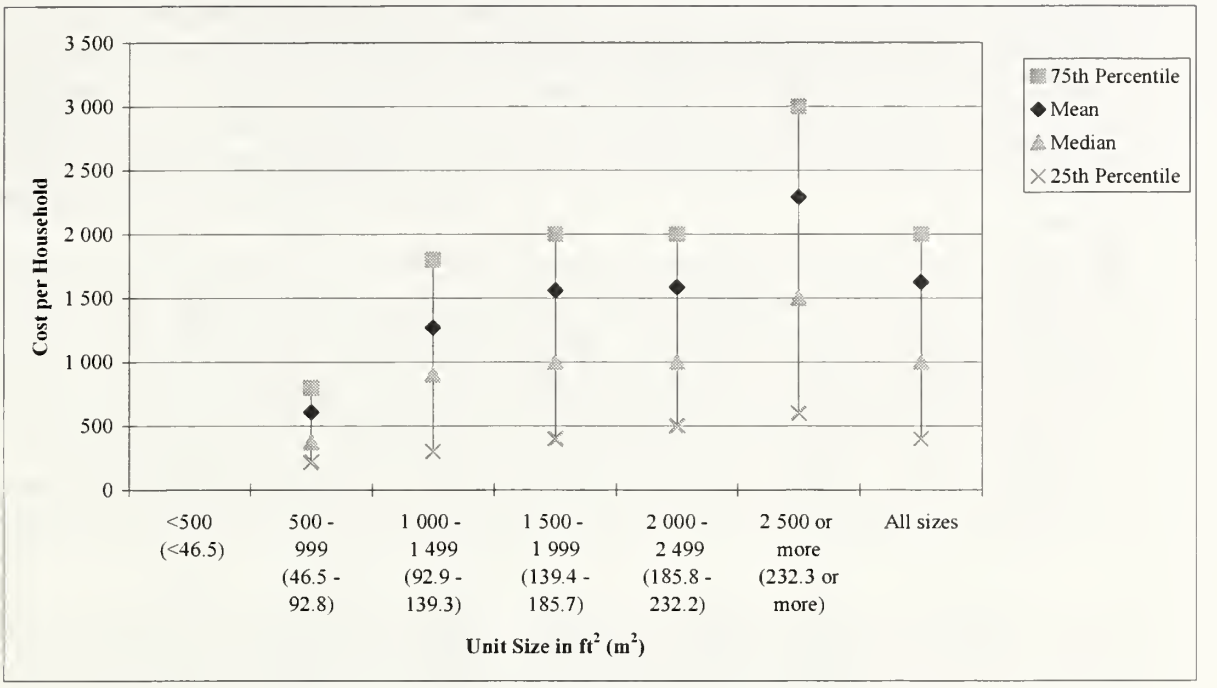

Table 5-14. Maintenance and Repairs to Finished Flooring (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	220	376	800	610
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	300	900	1 800	1 269
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	400	1 000	2 000	1 559
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	500	1 000	2 000	1 587
2 500 ft^2 or more (232.3 m^2 or more)	600	1 500	3 000	2 290
All sizes	400	1 000	2 000	1 626

Figure 5-14. Maintenance and Repairs to Finished Flooring (All Owner Occupied Units – Household Did the Work)

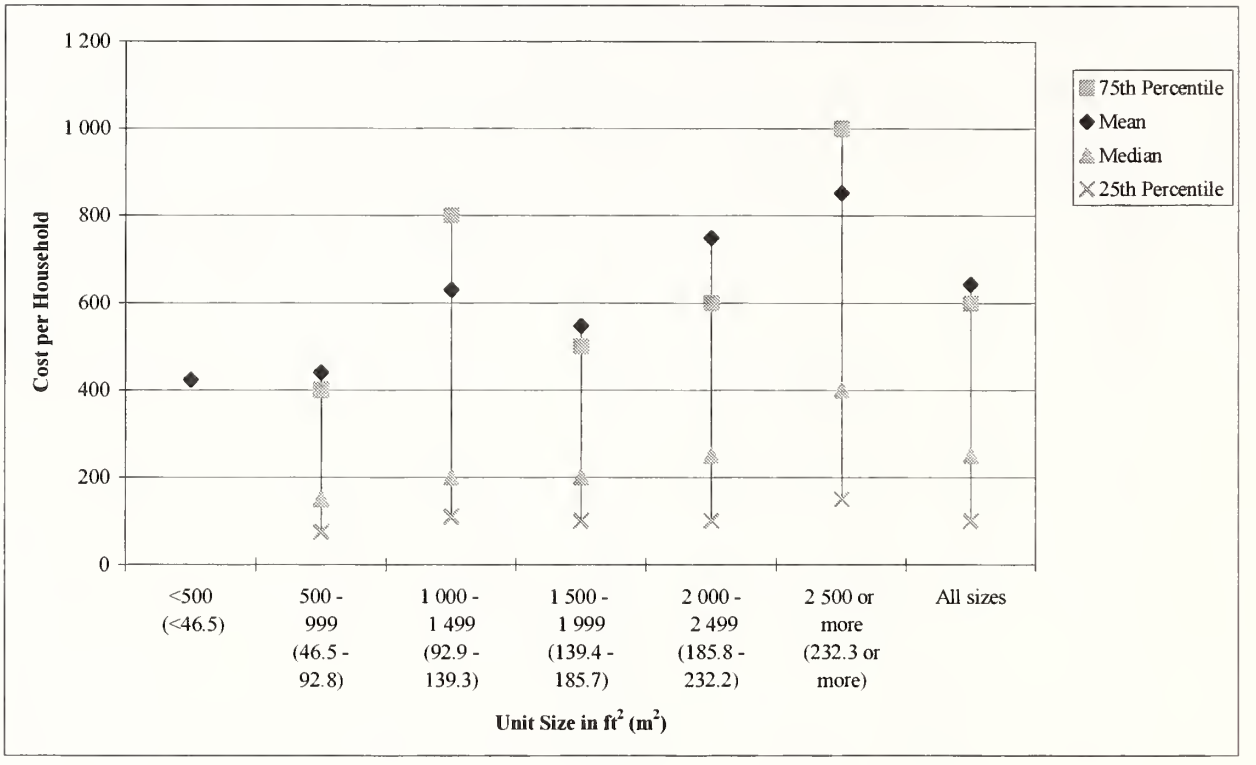

Table 5-15. Maintenance and Repairs to Finished Flooring (All Owner Occupied Units – Household Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	423
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	75	150	400	440
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	110	200	800	630
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	100	200	500	547
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	100	250	600	749
2 500 ft^2 or more (232.3 m^2 or more)	150	400	1 000	852
All sizes	100	250	600	643

The cost per household for maintenance and repairs to interior water pipes for all owner occupied units with a contractor doing the work is shown in Figure 5-15 and Table 5-16. The mean cost per household for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) is $326 and increases to $1 009 for a unit size of 2 500 ft^2 (232.3 m^2) or more. This is an increase of more than three times. The mean cost per household for all sizes is $640. Note that for several size categories the mean exceeds the 75th percentile (see Table 5-16). Thus, a number of very high cost observations are "pulling" up the value of the mean. The cost per household for all sizes is $80 for the 25th percentile, $220 for the median, and $500 for the 75th percentile.

Figure 5-16 and Table 5-17 show the cost per household for maintenance and repairs to interior water pipes for all owner occupied units with the household doing the work. The cost per household for the 25th percentile is $15 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2). For all other unit sizes, the 25th percentile cost per household remains constant at $20. The median cost per household also remains constant at $50 whenever the unit size is 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) or larger. The mean cost per household starts at $94 for a unit size less than 500 ft^2 (46.5 m^2) and increases to $140 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $113.

The cost per household for maintenance and repairs to siding for all owner occupied units with a contractor doing the work is shown in Figure 5-17 and Table 5-18. By looking at the figure and table, you can see that the lowest cost per household is $300 for the 25th percentile for a unit size of 1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2). The 25th percentile cost is $1 000 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The 25th percentile cost for all sizes is $400. The mean cost per household is $1 728 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $2 074 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $1 832.

Table 5-19 shows selected maintenance and repair costs of building elements by designation and statistical measure. The designation code shows that the building elements are for all owner occupied units, where either a contractor or the household did the work (i.e., codes AC and AH only). The mean cost per household for maintenance and repair of insulation with the household doing the work is $202. The mean cost per household for a contractor to do the work is $924. The mean cost per household to do maintenance and repair of fuse boxes or breaker switches with the household doing the work is $144. The mean cost for a contractor to do the work is $639.

5.2.3 Alterations

Interior alterations range from complete remodeling to the installation of an electrical service outlet. The key distinction between alterations within residential structures and major replacements is that major replacements are substitutions. For example, the installation of a bathtub, where there had not been one before, is an alteration, whereas the substitution of a new bathtub for an old one is a major replacement.

Figure 5-15. Maintenance and Repairs to Interior Water Pipes (All Owner Occupied Units – Contractor Did the Work)

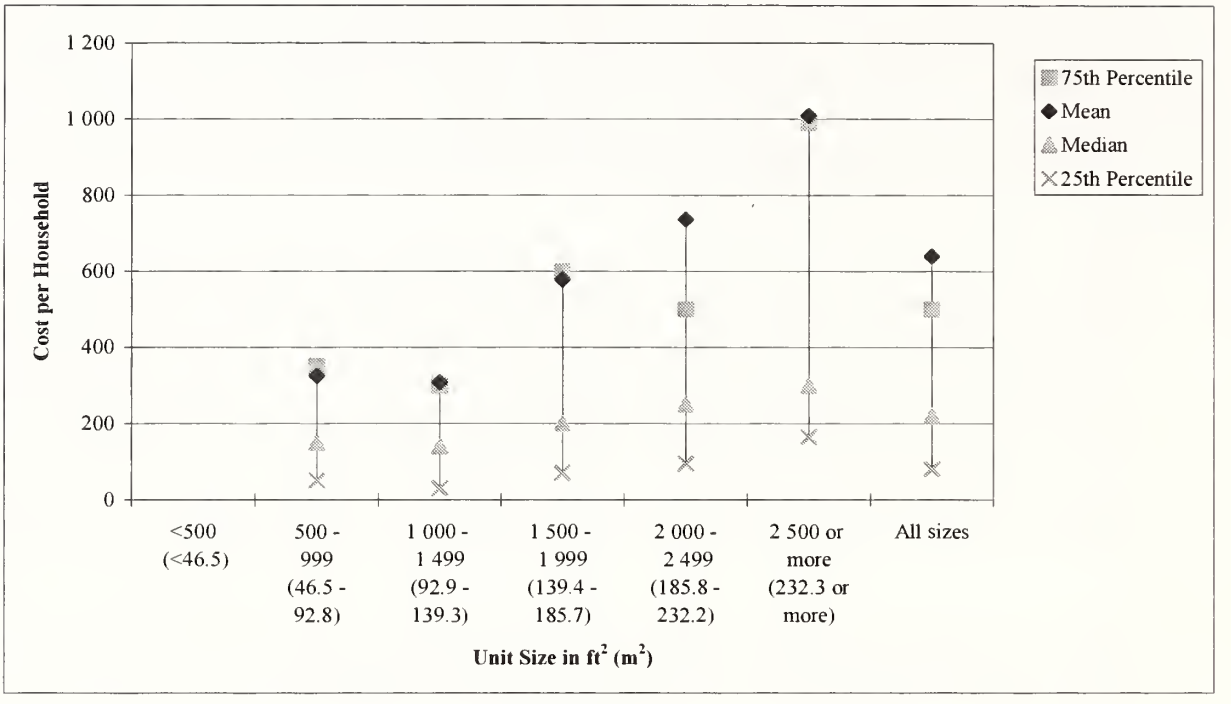

Table 5-16. Maintenance and Repairs to Interior Water Pipes (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	50	150	350	326
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	30	140	300	308
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	70	200	600	578
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	95	250	500	736
2 500 ft^2 or more (232.3 m^2 or more)	165	300	990	1 009
All sizes	80	220	500	640

Figure 5-16. Maintenance and Repairs to Interior Water Pipes (All Owner Occupied Units – Household Did the Work)

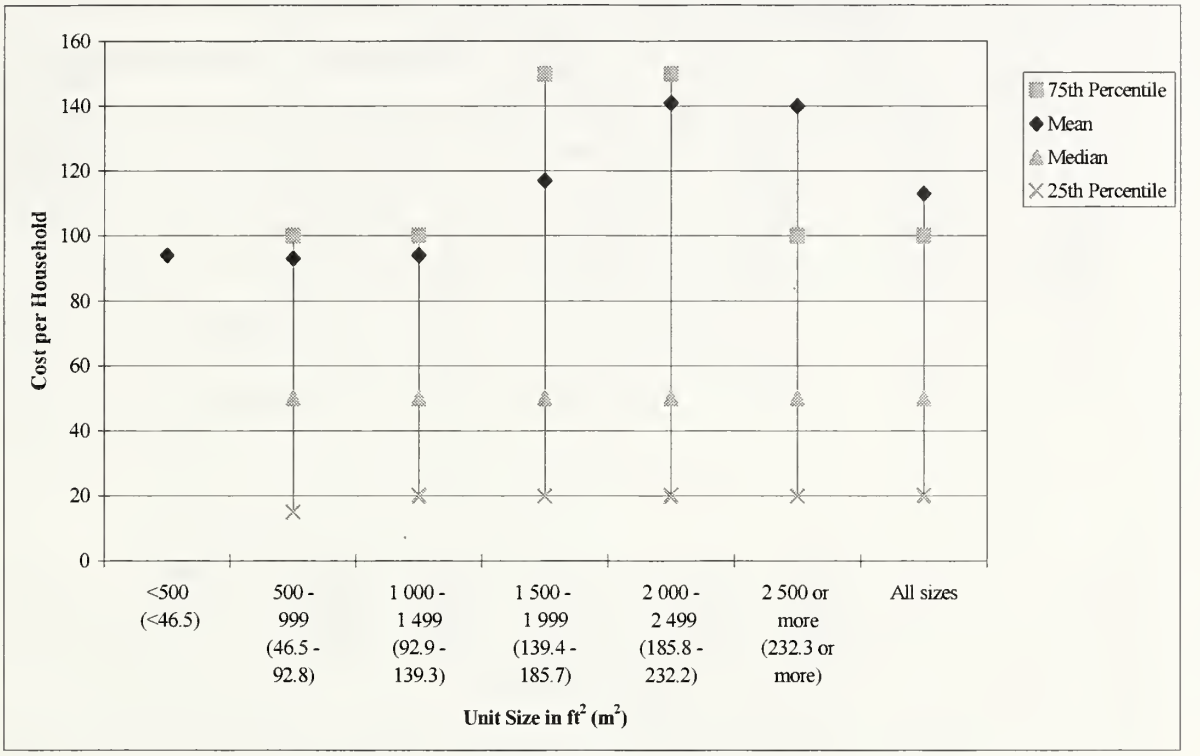

Table 5-17. Maintenance and Repairs to Interior Water Pipes (All Owner Occupied Units – Household Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	94
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	15	50	100	93
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	20	50	100	94
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	20	50	150	117
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	20	50	150	141
2 500 ft^2 or more (232.3 m^2 or more)	20	50	100	140
All sizes	20	50	100	113

Figure 5-17. Maintenance and Repairs to Siding (All Owner Occupied Units – Contractor Did the Work)

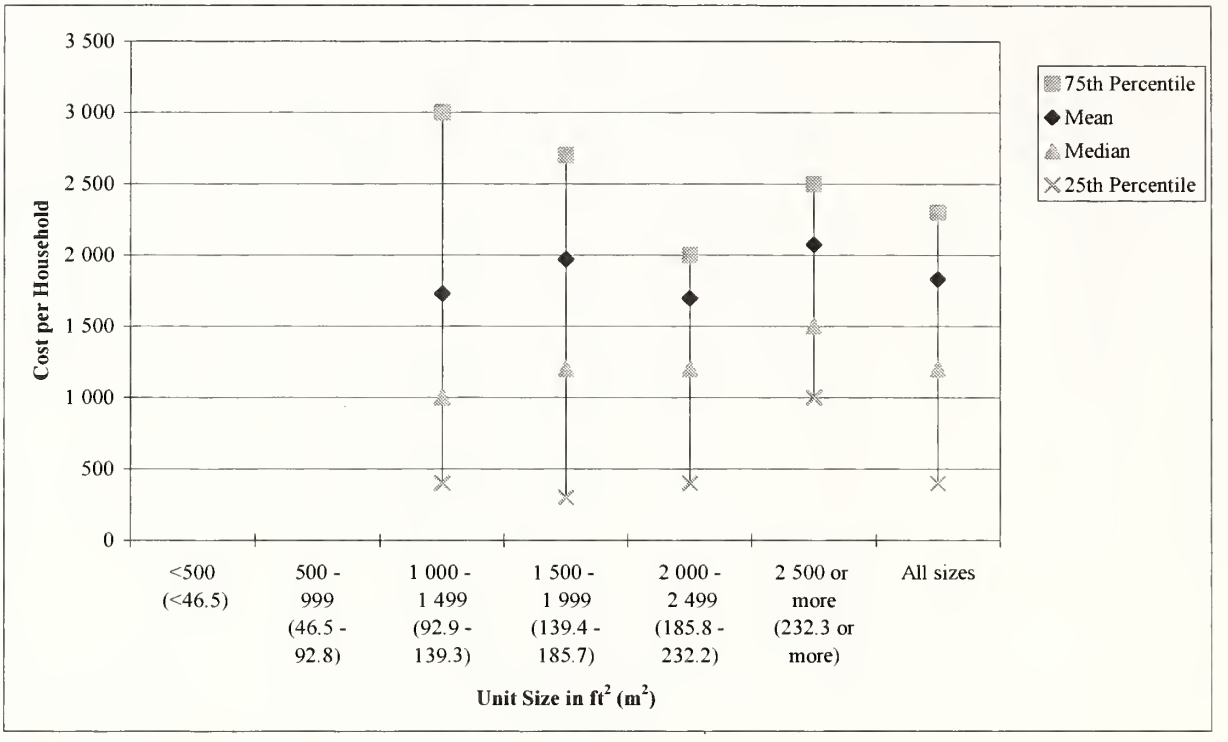

Table 5-18. Maintenance and Repairs to Siding (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	-
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	400	1 000	3 000	1 728
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	300	1 200	2 700	1 971
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	400	1 200	2 000	1 698
2 500 ft^2 or more (232.3 m^2 or more)	1 000	1 500	2 500	2 074
All sizes	400	1 200	2 300	1 832

Table 5-19. Selected Maintenance and Repair of Building Elements by Designation and the Cost per Household

Building Element	Designation	Cost per Household			
		25th Percentile	Median	75th Percentile	Mean
Siding	AH	100	250	600	578
Insulation	AC	0	300	1 500	924
Insulation	AH	50	100	400	202
Ceiling tiles	AC	100	500	1 100	1 051
Ceiling tiles	AH	60	200	400	282
Fuse boxes or breaker switches	AC	75	300	700	639
Fuse boxes or breaker switches	AH	18	50	175	144

Figure 5-18 and Table 5-20 show the cost per household for alterations within the residential structure to kitchen cabinets for all owner occupied units with a contractor doing the work. The median cost per household is $3 000 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and the median cost per household increases to $6 000 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The median cost for all sizes is $4 000. The mean cost per household is $2 900 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $9 318 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $5 914.

If the household does the work, the costs for alterations within the residential structure to kitchen cabinets are much lower as is shown in Figure 5-19 and Table 5-21. The mean cost per household is $1 588 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $2 944 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $2 399.

Figure 5-20 and Table 5-22 show the cost per household for alterations within the residential structure to kitchen flooring for all owner occupied units with a contractor doing the work. The cost per household for the 25th percentile is $500 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and remains constant through a unit size of 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2). The 25th percentile cost increases to $600 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The 25th percentile cost per household for all sizes is $500. The cost per household for the 75th percentile is $1 500 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $2 400 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The cost per household for all sizes is $2 000 for the 75th percentile while the mean cost per household is $1 467.

Figure 5-18. Alterations Within the Residential Structure to Kitchen Cabinets (All Owner Occupied Units – Contractor Did the Work)

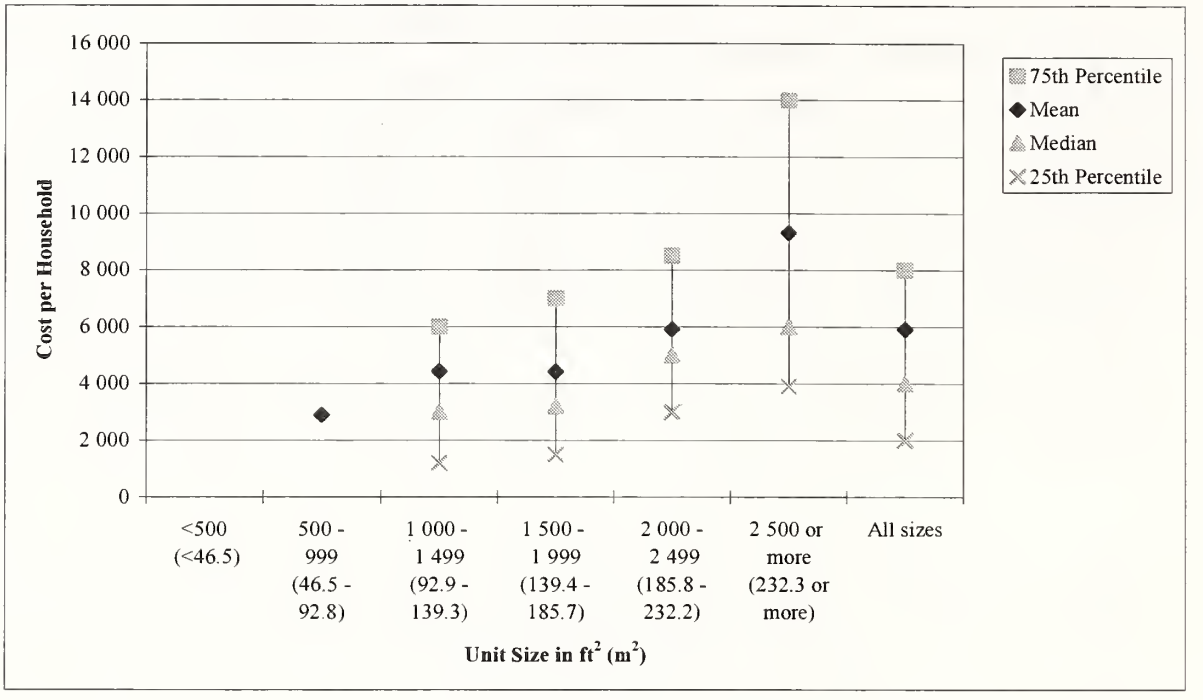

Table 5-20. Alterations Within the Residential Structure to Kitchen Cabinets (All Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	2 900
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	1 200	3 000	6 000	4 431
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	1 500	3 200	7 000	4 421
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	3 000	5 000	8 500	5 910
2 500 ft^2 or more (232.3 m^2 or more)	3 900	6 000	14 000	9 318
All sizes	2 000	4 000	8 000	5 914

Figure 5-19. Alterations Within the Residential Structure to Kitchen Cabinets (All Owner Occupied Units – Household Did the Work)

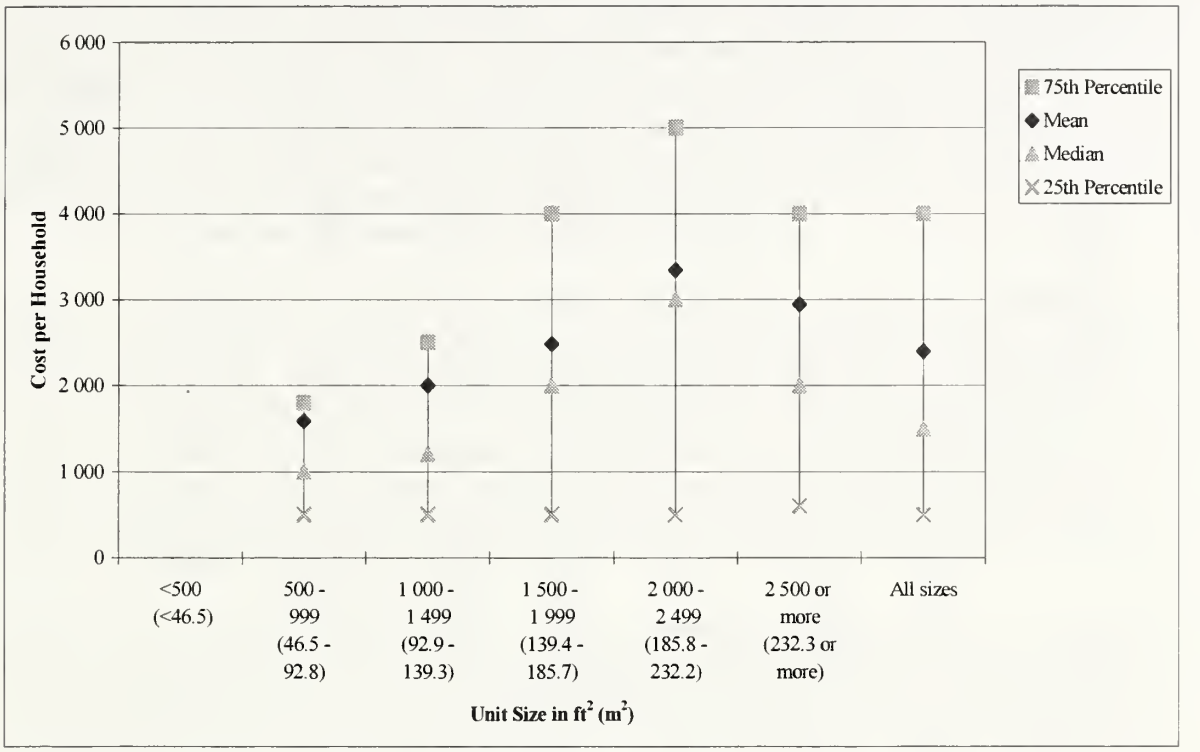

Table 5-21. Alterations Within the Residential Structure to Kitchen Cabinets (All Owner Occupied Units – Household Did the Work)

Unit Size in ft² (m²)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft² (Less than 46.5 m²)	-	-	-	-
500 ft² to 999 ft² (46.5 m² to 92.8 m²)	500	1 000	1 800	1 588
1 000 ft² to 1 499 ft² (92.9 m² to 139.3 m²)	500	1 200	2 500	2 000
1 500 ft² to 1 999 ft² (139.4 m² to 185.7 m²)	500	2 000	4 000	2 482
2 000 ft² to 2 499 ft² (185.8 m² to 232.2 m²)	500	3 000	5 000	3 342
2 500 ft² or more (232.3 m² or more)	600	2 000	4 000	2 944
All sizes	500	1 500	4 000	2 399

Figure 5-20. Alterations Within the Residential Structure to Kitchen Flooring (All Owner Occupied Units – Contractor Did the Work)

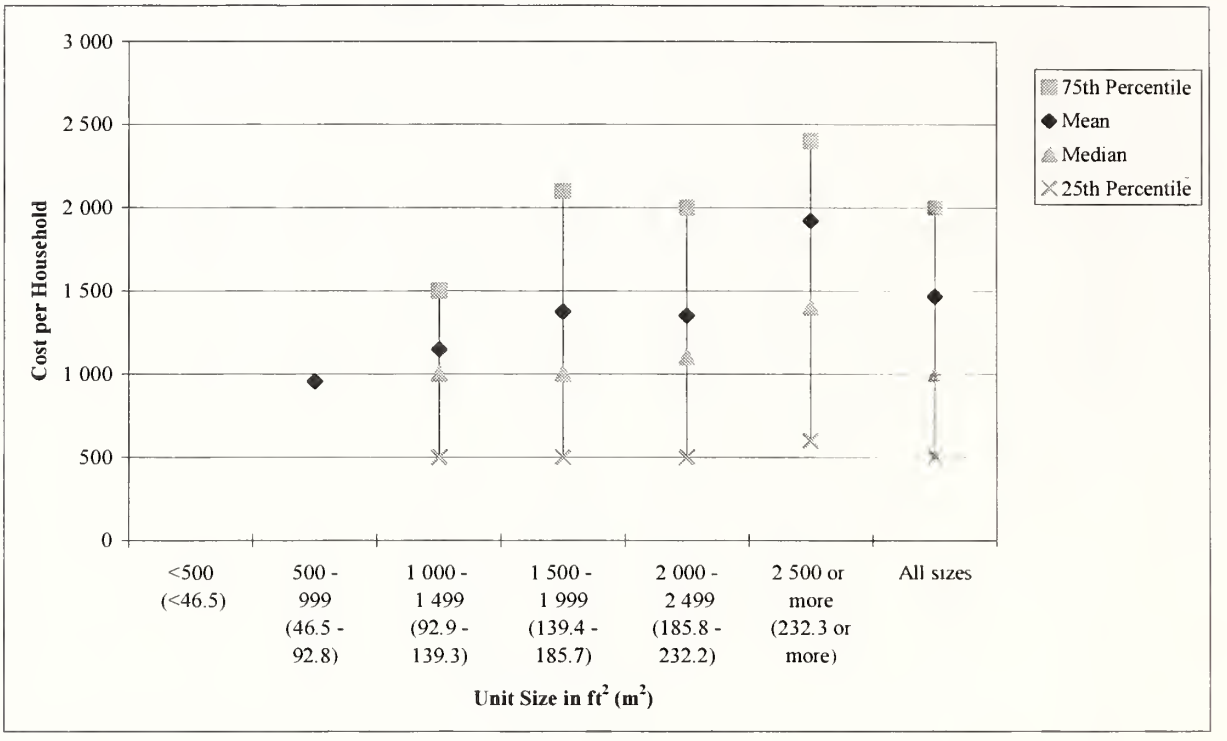

Table 5-22. Alterations Within the Residential Structure to Kitchen Flooring (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	955
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	500	1 000	1 500	1 146
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	500	1 000	2 100	1 375
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	500	1 100	2 000	1 351
2 500 ft^2 or more (232.3 m^2 or more)	600	1 400	2 400	1 923
All sizes	500	1 000	2 000	1 467

Figure 5-21 and Table 5-23 show the cost per household for all owner occupied units for alterations to kitchen counter tops with a contractor doing the work. The interquartile range is not reported for the two smallest size categories. The median cost is $262 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $1 000 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The median cost per household for all sizes is $700. The mean cost per household is $769 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and increases to $1 391 for the largest size category (i.e., 2 500 ft^2 (232.3 m^2) or more). The mean cost per household is slightly higher for the 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2) size category than for the largest size category (i.e., $1 468 versus $1 391). The mean cost per household is $1 046 for all sizes.

Figure 5-22 and Table 5-24 show the cost per household for alterations to bathroom cabinets for all owner occupied units with a contractor doing the work. The cost per household for the 25th percentile is $300 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $500 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The cost per household for the 75th percentile is $3 000 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $6 000 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The cost per household for the 75th percentile is $5 000 for all sizes. The mean cost per household for all sizes is $3 440.

Figure 5-23 and Table 5-25 show the cost per household for alterations to bathroom cabinets for all owner occupied units with the household doing the work. The median cost per household is $600 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2) and decreases to $450 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The 25th percentile shows a cost per household of $200 for all of the unit size categories. The mean cost per household for all sizes is $1 056.

Figure 5-24 and Table 5-26 show the cost per household for alterations to bathroom flooring for all owner occupied units with a contractor doing the work. The mean cost exhibits a pattern seen before; namely, cycles of increasing and decreasing costs as we move from the smaller to the larger size categories. The mean cost is $997 for a unit size of 500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2). The mean cost per household is $1 936 for a unit size of 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2). The mean cost per household for the largest size category (2 500 ft^2 (232.3 m^2) or more) decreases to $1 467. The mean cost per household for all sizes is $1 283. The cost per household for all sizes is $250 for the 25th percentile, $500 for the median, and $1 500 for the 75th percentile.

Figure 5-25 and Table 5-27 show the cost per household for alterations to bathroom counter tops for all owner occupied units with a contractor doing the work. The mean cost per household is $448 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $1 229 for a unit size of 2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2). The mean cost decreases to $1 035 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost per household for all sizes is $920. For all sizes, the cost per household is $100 for the 25th percentile, $300 for the median, and $1 000 for the 75th percentile.

Figure 5-21. Alterations Within the Residential Structure to Kitchen Counter Tops (All Owner Occupied Units – Contractor Did the Work)

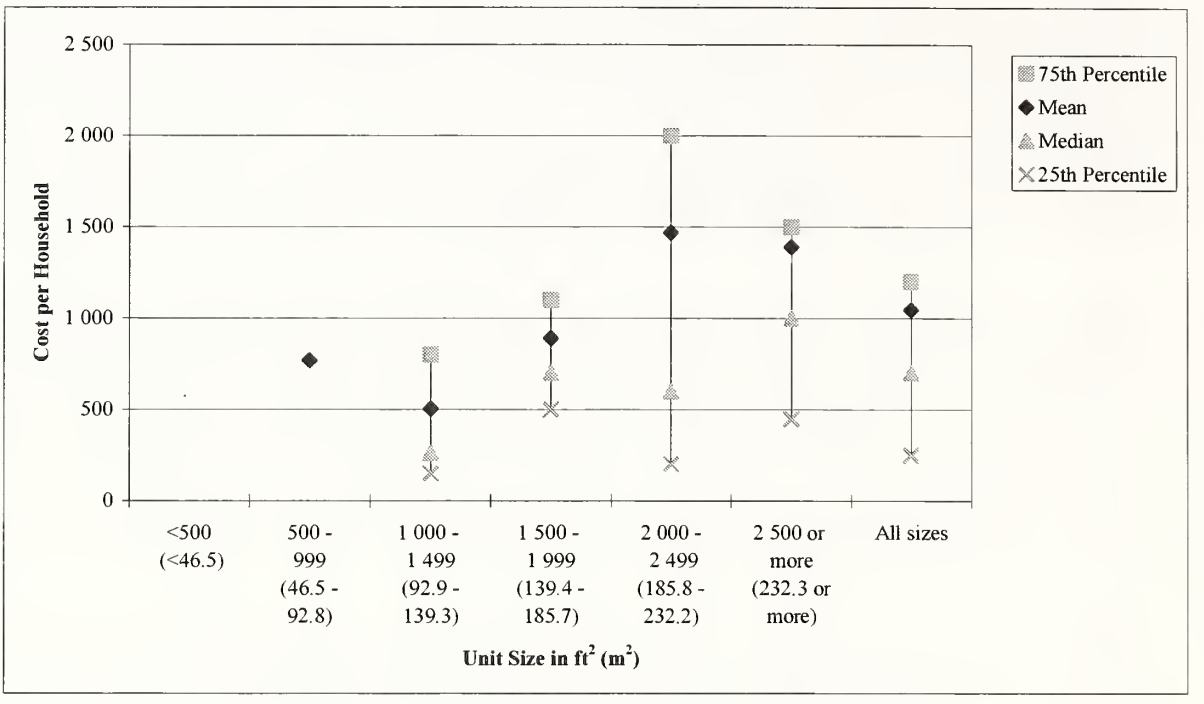

Table 5-23. Alterations Within the Residential Structure to Kitchen Counter Tops (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	769
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	150	262	800	503
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	500	700	1 100	890
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	200	600	2 000	1 468
2 500 ft^2 or more (232.3 m^2 or more)	450	1 000	1 500	1 391
All sizes	250	700	1 200	1 046

Figure 5-22. Alterations Within the Residential Structure to Bathroom Cabinets (All Owner Occupied Units – Contractor Did the Work)

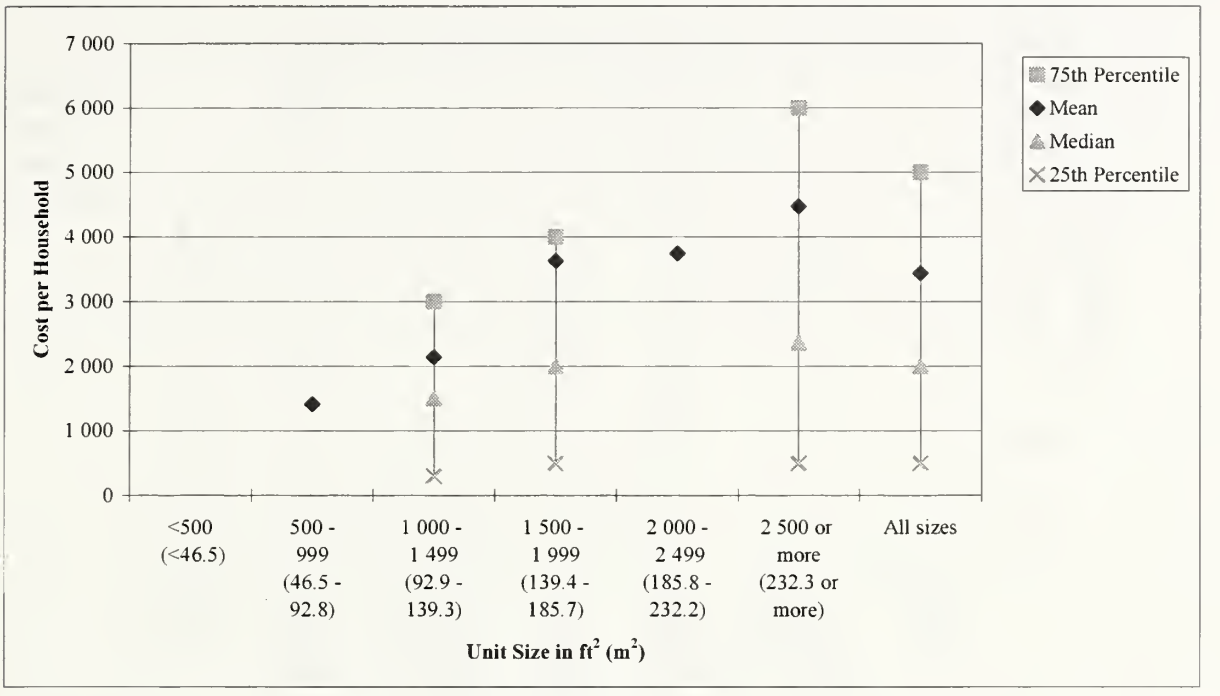

Table 5-24. Alterations Within the Residential Structure to Bathroom Cabinets (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft² (m²)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft² (Less than 46.5 m²)	-	-	-	-
500 ft² to 999 ft² (46.5 m² to 92.8 m²)	-	-	-	1 411
1 000 ft² to 1 499 ft² (92.9 m² to 139.3 m²)	300	1 500	3 000	2 139
1 500 ft² to 1 999 ft² (139.4 m² to 185.7 m²)	500	2 000	4 000	3 629
2 000 ft² to 2 499 ft² (185.8 m² to 232.2 m²)	-	-	-	3 748
2 500 ft² or more (232.3 m² or more)	500	2 362	6 000	4 475
All sizes	500	2 000	5 000	3 440

Figure 5-23. Alterations Within the Residential Structure to Bathroom Cabinets (All Owner Occupied Units – Household Did the Work)

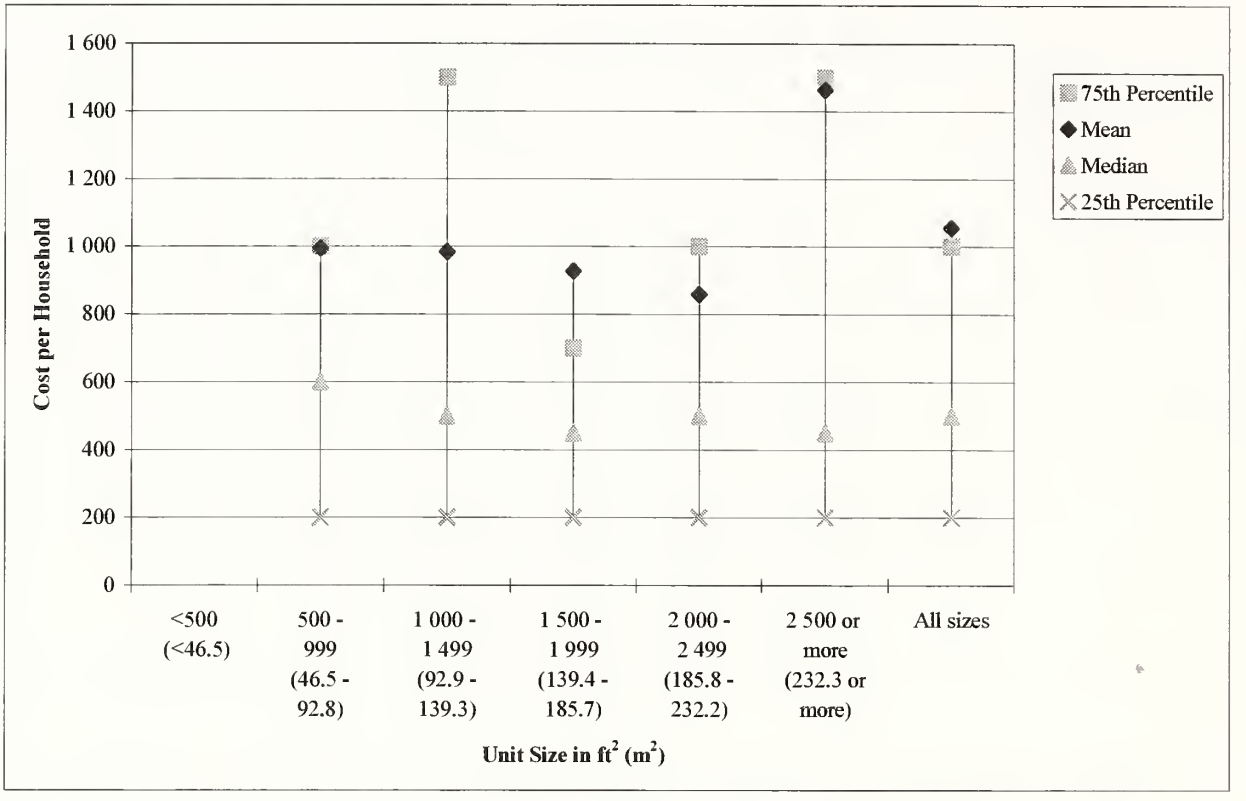

Table 5-25. Alterations Within the Residential Structure to Bathroom Cabinets (All Owner Occupied Units – Household Did the Work)

Unit Size in ft² (m²)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft² (Less than 46.5 m²)	-	-	-	-
500 ft² to 999 ft² (46.5 m² to 92.8 m²)	200	600	1 000	994
1 000 ft² to 1 499 ft² (92.9 m² to 139.3 m²)	200	500	1 500	984
1 500 ft² to 1 999 ft² (139.4 m² to 185.7 m²)	200	450	700	927
2 000 ft² to 2 499 ft² (185.8 m² to 232.2 m²)	200	500	1 000	859
2 500 ft² or more (232.3 m² or more)	200	450	1 500	1 463
All sizes	200	500	1 000	1 056

Figure 5-24. Alterations Within the Residential Structure to Bathroom Flooring (All Owner Occupied Units – Contractor Did the Work)

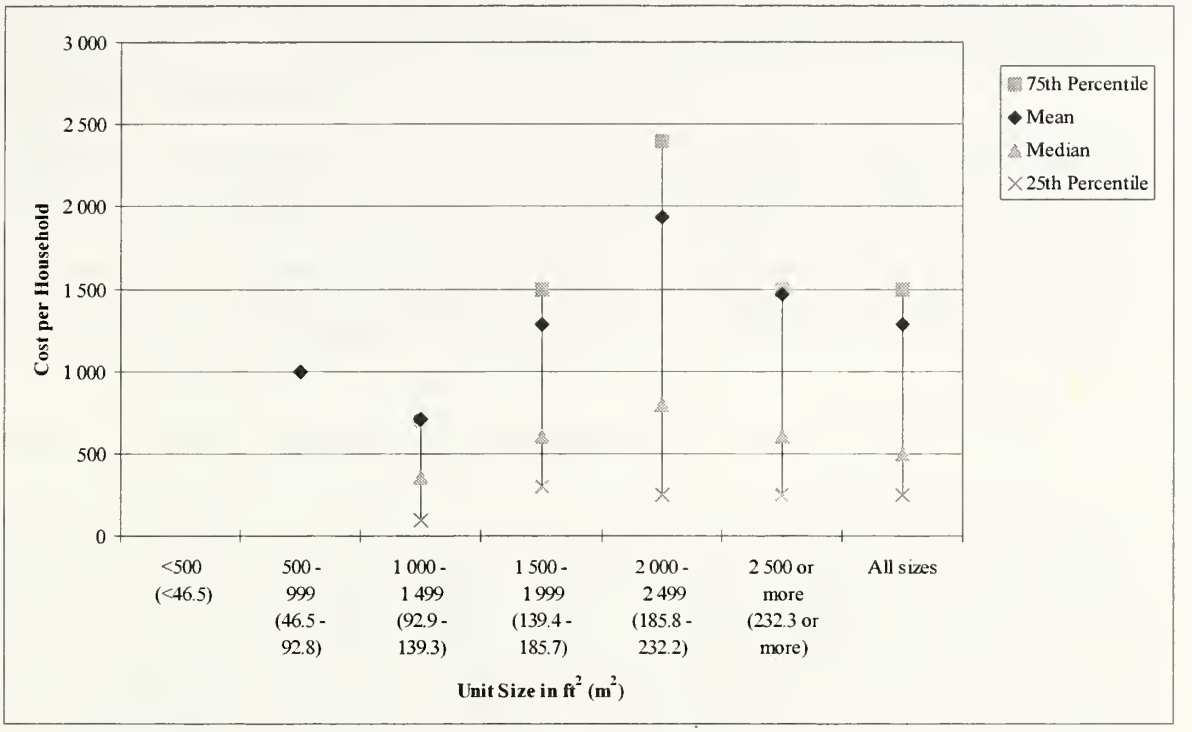

Table 5-26. Alterations Within the Residential Structure to Bathroom Flooring (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	997
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	100	350	700	711
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	300	600	1 500	1 287
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	250	800	2 400	1 936
2 500 ft^2 or more (232.3 m^2 or more)	250	600	1 500	1 467
All sizes	250	500	1 500	1 283

Figure 5-25. Alterations Within the Residential Structure to Bathroom Counter Tops (All Owner Occupied Units – Contractor Did the Work)

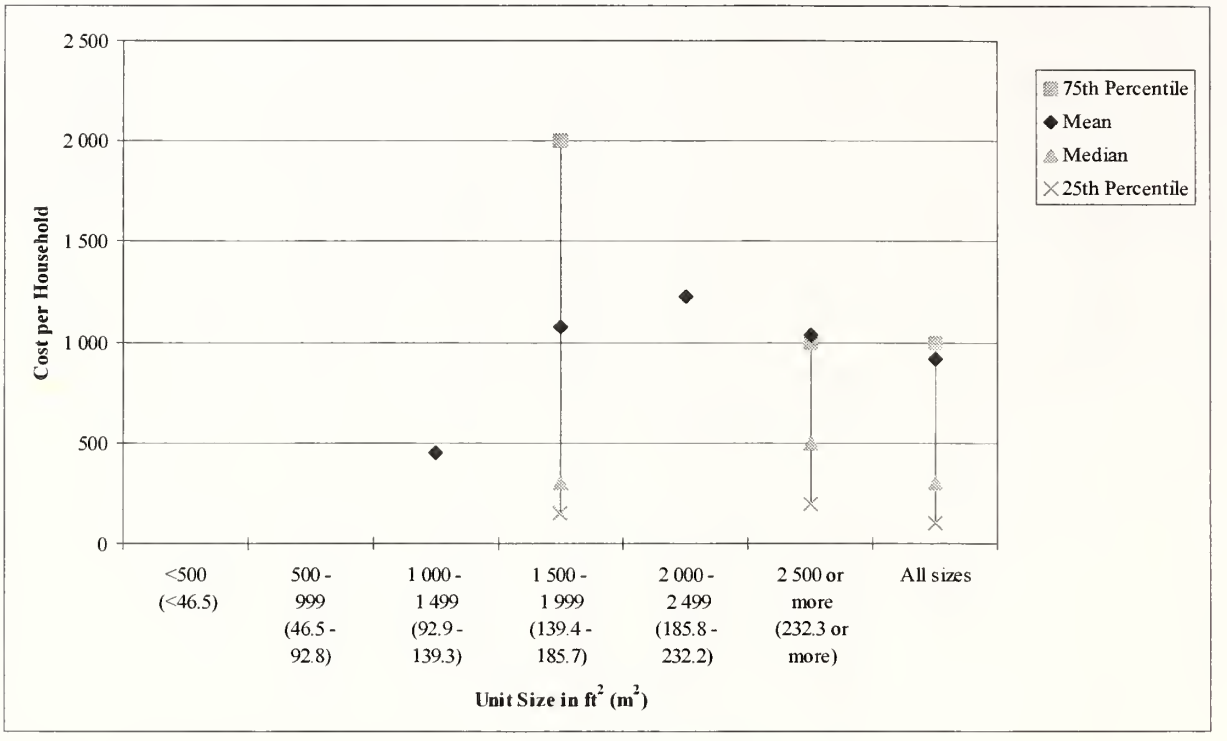

Table 5-27. Alterations Within the Residential Structure to Bathroom Counter Tops (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	-
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	-	-	-	448
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	150	300	2 000	1 074
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	-	-	-	1 229
2 500 ft^2 or more (232.3 m^2 or more)	200	500	1 000	1 035
All sizes	100	300	1 000	920

Figure 5-26 and Table 5-28 show the cost per household for alterations to bathroom tubs/showers for all owner occupied units with a contractor doing the work. The mean cost per household is $921 for a unit size of 1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2) and increases to $1 532 for a unit size of 2 500 ft^2 (232.3 m^2) or more. The mean cost for all sizes is $1 142. The cost per household for all sizes is $250 for the 25th percentile, $520 for the median, and $1 500 for the 75th percentile.

Table 5-29 shows selected alterations of building elements by designation and cost per household. The designation is for all owner occupied units with the household doing the work (i.e., code AH only). Looking at the table, one can see that the lowest mean cost per household is $318 for bathroom counter tops. The highest mean cost per household is $905 for kitchen flooring. The highest mean cost per household for doing alterations to the bathroom is $517 for bathroom tubs/showers.

5.2.4 Energy Expenditures Per Unit of Floor Area

Energy expenditures per unit of floor area as a function of the type of housing unit are classified in three ways. The first way (see Table 5-30) groups expenditures by tenure class (i.e., owner-occupied, rental, or all units). The second way (see Table 5-31) groups expenditures by end use (e.g., space heating or air-conditioning). The third way (see Table 5-32) groups expenditures by type of fuel (e.g., electricity, natural gas, or fuel oil). The tables presented in this section tabulate expenditures for five types of housing units: (1) single-family detached; (2) single-family attached; (3) multi-family, 2 to 4 units; (4) multi-family, 5 or more units; and (5) mobile homes. An aggregated total category is also displayed on each table; this category is labeled "all units."

Table 5-30 shows energy expenditures per unit of floor area by type of housing unit and tenure class for 1997. The table shows that the highest expenditures per ft^2 (m^2) are for rental units, with the exception of multi-family dwellings with 2 to 4 units. The highest energy expenditure per unit of floor area is $1.33/$ft^2$ ($14.29/$m^2$) for owner occupied multi-family dwellings with 2 to 4 units. The lowest energy expenditure per unit of floor area is $0.69/$ft^2$ ($7.43/$m^2$) for owner-occupied dwellings with 5 or more units. Energy expenditures per unit of floor area for all units, owner occupied and rental combined, are $0.93/$ft^2$ ($10.04/$m^2$).

Note that the energy expenditure values recorded in the last column of Table 5-30 vary considerably as a function of the type of housing unit, with multi-family dwellings with 2 to 4 units the highest—$1.26/$ft^2$ ($13.51/$m^2$)—and multi-family dwellings with 5 or more units the lowest—$0.88/$ft^2$ ($9.51/$m^2$). The same dollar values that appear under the "All Units" heading also appear under the "All End Uses" or "All Fuels" headings in Tables 5-31 and 5-32, respectively. These values are conditional only on the type of housing unit, whereas the values recorded in Table 5-30 under the "Owner-Occupied" or "Rental" headings are conditional on the type of occupant. The distinction between conditional and unconditional values becomes more important as expenditures by end use and fuel type are examined. These values are recorded in Tables 5-31 and 5-32.

Figure 5-26. Alterations Within the Residential Structure to Bathroom Tub/Shower (All Owner Occupied Units – Contractor Did the Work)

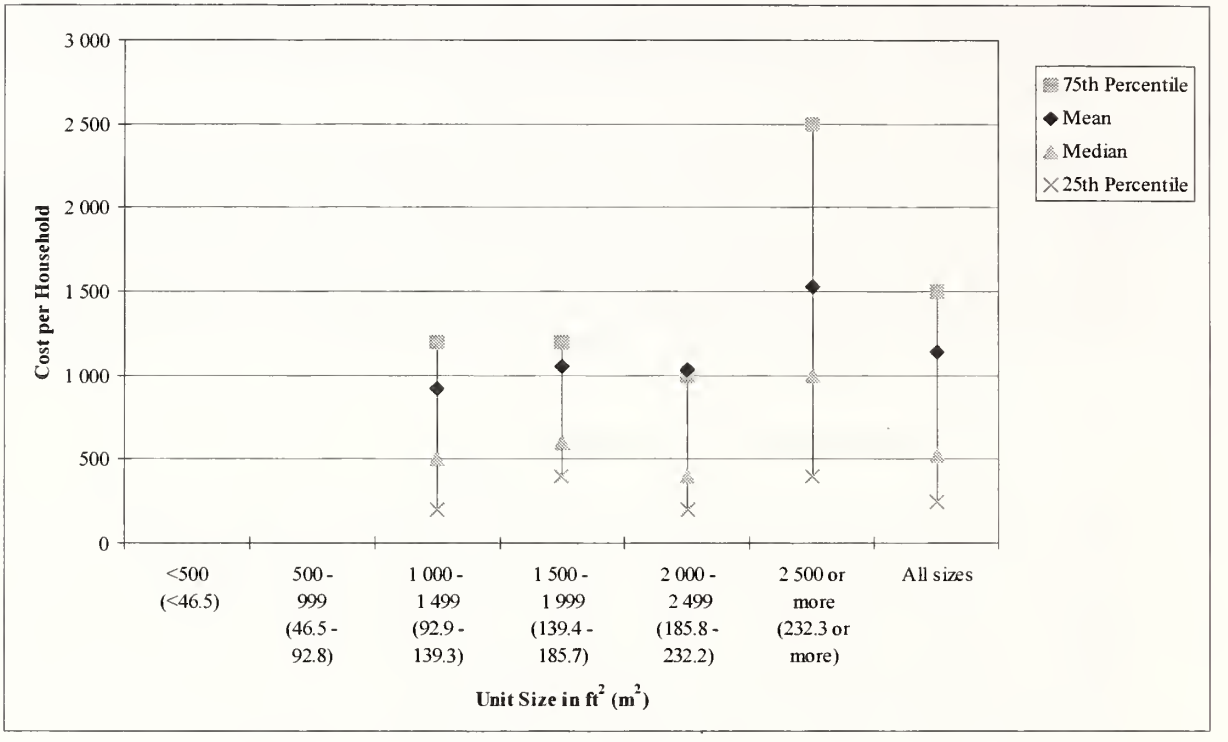

Table 5-28. Alterations Within the Residential Structure to Bathroom Tub/Shower (All Owner Occupied Units – Contractor Did the Work)

Unit Size in ft^2 (m^2)	Cost per Household			
	25th Percentile	Median	75th Percentile	Mean
Less than 500 ft^2 (Less than 46.5 m^2)	-	-	-	-
500 ft^2 to 999 ft^2 (46.5 m^2 to 92.8 m^2)	-	-	-	-
1 000 ft^2 to 1 499 ft^2 (92.9 m^2 to 139.3 m^2)	200	500	1 200	921
1 500 ft^2 to 1 999 ft^2 (139.4 m^2 to 185.7 m^2)	400	600	1 200	1 052
2 000 ft^2 to 2 499 ft^2 (185.8 m^2 to 232.2 m^2)	200	400	1 000	1 034
2 500 ft^2 or more (232.3 m^2 or more)	400	1 000	2 500	1 532
All sizes	250	520	1 500	1 142

Table 5-29. Selected Alterations Within the Residential Structure of Building Elements by Designation and the Cost per Household

Building Element	Designation	Cost per Household			
		25th Percentile	Median	75th Percentile	Mean
Kitchen flooring	AH	200	400	1 000	905
Kitchen counter tops	AH	139	300	500	637
Bathroom flooring	AH	95	200	500	508
Bathroom counter tops	AH	70	150	300	318
Bathroom tub/shower	AH	200	300	500	517

Table 5-30. Energy Expenditures per Unit of Floor Area by Type of Housing Unit and Tenure Class: 1997

Type of Housing Unit	Tenure Class					
	Owner-Occupied		Rental		All Units	
	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2
Single-Family Detached	0.89	9.53	1.04	11.22	0.90	9.69
Single-Family Attached	0.97	10.49	1.12	12.02	1.03	11.07
Multi-Family, 2 to 4 units	1.33	14.29	1.23	13.27	1.26	13.51
Multi-Family, 5 or more units	0.69	7.43	0.90	9.74	0.88	9.51
Mobile Home	1.16	12.54	1.36	14.60	1.19	12.82
All Units	0.91	9.76	1.03	11.10	0.93	10.04

Table 5-31 shows energy expenditures by type of housing unit and end use for 1997. Five "specific" end use categories are covered plus an aggregated "all end uses" category. The end use categories are space heating, air-conditioning, water heating, refrigerators, other appliances and lighting, and all end uses. With the exception of air-conditioning, almost all housing units employ each of the four remaining "specific" end uses of energy (see Table 3-11 in section 3.3). Overall (see the "All Units" row under the "Type of Housing Unit" heading), refrigerators have the lowest end use cost ($0.08/ft^2 ($0.90/m^2)), while other appliances and lighting have the highest end use cost ($0.36/ft^2 ($3.84/m^2)). Multi-family dwellings with 5 or more units have the lowest end use costs for space heating ($0.18/ft^2 ($1.92/m^2)) and other appliances and lighting ($0.33/ft^2 ($3.59/m^2)). Single-family detached units have the lowest end use costs for air-conditioning, water heating, and refrigerators, and the second lowest for space heating and other appliances and lighting. Multi-family dwellings with 2 to 4 units have the highest end use cost for space heating ($0.49/ft^2 ($5.30/m^2)), while mobile homes have the highest end use cost for air-conditioning ($0.17/ft^2 ($1.79/m^2)) and other appliances and lighting ($0.43/ft^2 ($4.58/m^2)).

Table 5-31. Energy Expenditures by Type of Housing Unit and End Use: 1997

Type of Housing Unit	End Use											
	Space Heating		Air-Conditioning		Water Heating		Refrigerators		Other Appliances and Lighting		All End Uses	
	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2
Single-Family Detached	0.28	3.06	0.09	0.97	0.12	1.30	0.08	0.84	0.35	3.80	0.90	9.69
Single-Family Attached	0.36	3.85	0.09	1.00	0.15	1.65	0.09	0.97	0.36	3.92	1.03	11.07
Multi-Family, 2 to 4 units	0.49	5.30	0.09	0.95	0.20	2.13	0.11	1.23	0.39	4.24	1.26	13.51
Multi-Family, 5 or more units	0.18	1.92	0.12	1.26	0.19	2.09	0.11	1.14	0.33	3.59	0.88	9.51
Mobile Home	0.35	3.76	0.17	1.79	0.21	2.28	0.09	0.98	0.43	4.58	1.19	12.82
All Units	0.29	3.12	0.10	1.03	0.14	1.46	0.08	0.90	0.36	3.84	0.93	10.04

Table 5-32. Energy Expenditures by Type of Housing Unit and Type of Fuel: 1997

Type of Housing Unit	Type of Fuel											
	Electricity		Natural Gas		Fuel Oil		Kerosene		LPG		All Fuels	
	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2
Single-Family Detached	0.58	6.29	0.37	3.97	0.49	5.24	0.08	0.88	0.31	3.38	0.90	9.69
Single-Family Attached	0.62	6.64	0.53	5.69	0.73	7.83	0.10	1.05	0.52	5.58	1.03	11.07
Multi-Family, 2 to 4 units	0.72	7.74	0.68	7.32	0.86	9.30	0.09	0.94	0.66	7.09	1.26	13.51
Multi-Family, 5 or more units	0.67	7.17	0.34	3.66	0.37	4.03	0.04	0.46	0.29	3.08	0.88	9.51
Mobile Home	0.89	9.61	0.46	4.95	0.39	4.17	0.28	3.05	0.43	4.66	1.19	12.82
All Units	0.61	6.59	0.39	4.23	0.50	5.39	0.10	1.12	0.34	3.62	0.93	10.04

Table 5-32 shows energy expenditures by type of housing unit and type of fuel for 1997. Five "specific" type of fuel categories are covered plus an aggregated "all types" category. The six type of fuel cost categories are electricity, natural gas, fuel oil, kerosene, LPG, and all fuels. Note that electricity is the only fuel type used in all types of housing units (see Table 3-12 in section 3.3). Thus, the costs for the four remaining "specific" types of fuel are all "conditional." Consequently, the cost appearing under the heading "All Fuels" for each type of housing unit is not the sum of the specific types of fuel. When all units are considered (see the "All Units" row under the "Type of Housing Unit" heading), electricity is the fuel type with the highest cost, $0.61/ft^2 ($6.59/m^2), and kerosene at $0.10/ft^2 ($1.12/m^2) has the lowest cost. When each type of housing unit is examined, the highest cost type of fuel is electricity for single-family detached units ($0.58/ft^2 ($6.29/m^2)), multi-family dwellings with 5 or more units ($0.67/ft^2 ($7.17/m^2)), and mobile homes ($0.89/ft^2 ($9.61/m^2)), and fuel oil for single-family attached units ($0.73/ft^2 ($7.83/m^2)), and multi-family dwellings with 2 to 4 units ($0.86/ft^2 ($9.30/m^2)).

5.3 Summary of Baseline Measures of Durability-Related Costs

This section summarizes the baseline measures of durability-related costs that are presented in sections 5.2.1, 5.2.2, 5.2.3, and 5.2.4 of this document. These measures are presented in Table 5-33.

The table is organized to serve as a quick reference; it consists of two parts. Part A reports costs by building element on a per household basis. Building elements are grouped under three cost categories—major replacements, maintenance and repair, and alterations. The remaining column headings under Part A of Table 5-33 are identical to those in Tables 5-13, 5-19, and 5-29. Part B reports energy expenditures per unit of floor area. Energy expenditures in both $/ft^2 and $/m^2 are reported. Both aggregated (e.g., all fuels) and disaggregated (electricity) values are reported.

Table 5-33. Summary of Baseline Measures of Durability-Related Costs

Part A: By Cost Element per Household

Building Element	Designation	Cost per Household			
		25th Percentile	Median	75th Percentile	Mean
Major Replacements					
Roof	AC	1 800	2 700	4 500	3 667
Roof	SC	1 800	2 800	4 500	3 743
Roof	AH	700	1 300	2 500	1 829
Roof	SH	800	1 400	2 500	1 873
Doors or windows	AC	300	951	2 550	2 012
Doors or windows	SC	350	1 000	2 900	2 108
Doors or windows	AH	120	250	600	590
Doors or windows	SH	120	300	600	628
All siding	AC	3 000	5 419	8 900	6 433
All siding	AH	1 000	2 000	3 000	2 935
Furnace, heat pump, or boiler and maintenance and repair of furnace/heating equipment parts	AC	1 000	1 800	2 700	2 058
Central air conditioning	AC	1 500	2 400	3 500	2 624
Maintenance and Repair					
Finished flooring	AC	400	1 000	2 000	1 626
Finished flooring	AH	100	250	600	643
Interior water pipes	AC	80	220	500	640
Interior water pipes	AH	20	50	100	113
Siding	AC	400	1 200	2 300	1 832
Alterations					
Kitchen cabinets	AC	2 000	4 000	8 000	5 914
Kitchen cabinets	AH	500	1 500	4 000	2 399
Kitchen flooring	AC	500	1 000	2 000	1 467
Kitchen counter tops	AC	250	700	1 200	1 046
Bathroom cabinets	AC	500	2 000	5 000	3 440
Bathroom cabinets	AH	200	500	1 000	1 056
Bathroom flooring	AC	250	500	1 500	1 283
Bathroom counter tops	AC	100	300	1 000	920
Bathroom tub/shower	AC	250	520	1 500	1 142

Table 5-33. Summary of Baseline Measures of Durability-Related Costs (continued)

Part B: Key Energy Expenditures per Unit of Floor Area

Type of Expenditure	Energy Expenditure	
	$/ft^2	$/m^2
Total	0.93	10.04
End Use		
Space heating	0.29	3.12
Air-conditioning	0.10	1.03
Water heating	0.14	1.46
Refrigerators	0.08	0.90
Other appliances and lighting	0.36	3.84
All end uses	0.93	10.04
Types of Fuel		
Electricity	0.61	6.59
Natural gas	0.39	4.23
Fuel oil	0.50	5.39
Kerosene	0.10	1.12
LPG	0.34	3.62
All fuels	0.93	10.04

6. Summary and Suggestions for Further Research

6.1 Summary

This report examines the key sources of construction industry data and extracts from them a single, consistent set of baseline measures that can be used to monitor progress towards achieving the PATH vision of improving housing durability and reducing maintenance costs by 50 % by 2010. Specifically, the report describes the key construction industry data sources and their associated data elements, demonstrates how each data source provides perspective on one or more dimensions of the construction industry, and synthesizes key data elements into a common format for specifying the baseline measures for improving housing durability.

This document has six chapters. Chapter 1 explains the purpose, scope, and general approach. Chapter 2 introduces the PATH vision and describes how a well-defined set of metrics is used to develop the baseline measures. The averages of current practice—defined in this report as industry performance in 1997—are used to develop the baseline measures for improving housing durability. Chapter 3 provides an overview of construction industry data. The overview provides the context within which the baseline measures for improving housing durability are developed. Chapter 4 presents the baseline measures of service life for selected building elements. Key baseline measures of service life are summarized in Table 4-4, which appears at the end of Chapter 4. Chapter 5 presents the baseline measures of durability-related costs. Specific cost categories covered include major replacements, maintenance and repair, and alterations. Information on energy expenditures is also presented. Key baseline measures of durability-related costs are summarized in Table 5-33, which appears at the end of Chapter 5. Chapter 6 concludes the document with a summary and suggestions for further research.

6.2 Suggestions for Further Research

The work for this document uncovered areas of research that might be of value to government agencies and private sector organizations that are concerned about improving durability and reducing maintenance costs. These areas are concerned with: (1) the dissemination of detailed information on service life data and durability-related costs for selected building elements; (2) the use of life-cycle cost analysis as a means of combining service life data and durability-related costs into a coherent format for choosing among alternative building materials, components, and systems; (3) the treatment of interdependencies between building components and systems; and (4) the measurement and evaluation of progress toward achievement of the PATH vision.

The equipment life and maintenance cost survey published in the October 1978 issue of the *ASHRAE Journal*[50] provides a benchmark for the type of detailed information on

[50] Akalin, Mustafat T. 1978. "Equipment Life and Maintenance Cost Survey." *ASHRAE Journal* (October): pp. 39-44.

service life data and durability-related costs that is needed for selected building elements. This early effort is noteworthy in that it provided not only expected values (i.e., the mean) for equipment service lives but ranges of values that included the 25th percentile, the median (i.e., 50th percentile), the 75th percentile, and the mode (i.e., the most frequently observed value). Ranges of values for maintenance costs per unit of floor area were also provided for a variety of maintenance scenarios. The article also provided definitions for equipment elements and maintenance policies, which proved useful in subsequent studies. The 1978 *ASHRAE Journal* article provided a framework for fact-based facility management programs, including an in-depth analysis of alternative replacement strategies for aging plant and facility equipment at NIST, formerly the National Bureau of Standards.[51] Unfortunately, it would be many years before others in the commercial buildings sector emulated the ASHRAE equipment life and maintenance cost survey.

More recent work focusing on the residential sector is the National Family Opinion (NFO) Survey, a nationwide survey sponsored by the National Association of Home Builders (NAHB). As the NFO Survey reaches maturity, it will prove an excellent source of service life data, because the survey instrument contains a series of questions on housing type, floor space, geographic location, types of exterior enclosure, and types of replacements. These questions will enable researchers at NIST and elsewhere to derive empirical estimates of service lives for key building elements based on well-defined subsets of the survey data. The survey instrument also includes questions on expenditures for housing improvements (e.g., additions, alterations, and major replacements). These data are currently under analysis and are planned for incorporation into a software product that NIST is developing for the PATH program. Furthermore, as the NFO Survey database grows, it will become possible to produce ranges of values for service lives and replacement costs. Ultimately, the NFO Survey database will produce distributions of service life data and replacement cost data for key building elements. For example, if a distribution of replacement cost data for selected building elements is available, a potential software user could determine where their estimated replacement cost falls within the overall distribution for that building element.

Chapters 4 and 5 presented information on service lives and durability-related costs for a wide variety of building elements. This information indicated that both service lives and durability-related costs varied considerably. Because increasing a building element's service life will lead to less frequent replacements, it may prove advantageous for the homeowner, or other designated decision maker, to select a longer-lived product for installation. What is needed is a comprehensive approach for determining when it is economically efficient to invest in the longer-lived product. Life-cycle cost analysis provides such a comprehensive approach. Life-cycle cost analysis measures, in present value or annual value terms, the sum of all relevant costs associated with owning, operating, and disposing of a building, building system, or associated building materials, or a combination thereof, over a specified time period, referred to as the study period. Thus, life-cycle cost analysis provides a framework for "smoothing" out the irregular

[51] Chen, Phillip T., and Robert E. Chapman. 1981. "Budget Estimates for Replacement of Plant and Facility Equipment at the National Bureau of Standards." *ASHRAE Transactions* (April): pp. 1243-1258.

cash flows associated with durability-related expenditures into "annual value" terms. In addition, life-cycle cost analysis is supported by an industry consensus standard published by the American Society for Testing and Materials (ASTM).[52] Finally, life-cycle cost analysis can be used in conjunction with a sensitivity analysis to capture information on variations in both costs and service lives. A recently published ASTM guide[53] demonstrates how to apply life-cycle cost analysis to a durability-related investment decision. The ASTM guide employed both a traditional sensitivity analysis and Monte Carlo techniques to demonstrate how to evaluate investment alternatives with different service lives (i.e., replacement schedules), maintenance costs, and installation costs.

The information contained in this report is in a form that supports a wide variety of life-cycle cost analyses. For example, if a homeowner were planning on replacing an existing hot water heater, their decision would be based on a number of factors. These factors include, but are not limited to, unit cost, anticipated service life, annual energy costs, and the homeowner's time horizon and their time-value of money. Information on the durability-related factors—unit costs, anticipated service life, and energy costs—is contained in Chapters 5, 4, and 3, respectively. Information on establishing the homeowner's time horizon and time-value of money (i.e., discount rate) is available through reference to the life-cycle cost literature (e.g., ASTM E 917).

Consider the following case illustration where the homeowner has limited their choices to two generic grades of hot water heaters. The homeowner has a 20-year time horizon and a 5 % real discount rate. The homeowner's choice is between two alternatives. The first alternative corresponds to a standard-grade hot water heater; it costs $416, the average unit cost for hot water heaters (see Table 5-13), is expected to last 12 years (see the ranges of values presented in Table 4-4), and will result in an annual energy cost of $196, the annual average for hot water heaters (see Table 3-11). The second alternative corresponds to a premium-grade hot water heater; it costs $500, the 75th percentile unit cost for hot water heaters (see Table 5-13), is expected to last 15 years (see Table 4-4), and will result in an annual energy cost of $180, an 8 % reduction from the average cost of $196. Because the homeowner's time horizon is 20 years, both alternatives will require replacement before the end of the study period. The estimated replacement cost is $416 for the first alternative and $500 for the second alternative. At the end of the study period, each alternative will have a residual value indicating that it has not reached the end of its service life. Performing the life-cycle cost calculations over the 20-year study period using a 5 % discount rate, results in a life-cycle cost of $3 038 for the first alternative and $2 858 for the second alternative. Thus, the premium-grade hot water heater should be selected because it results in the lowest life-cycle cost for the homeowner.

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[52] American Society for Testing and Materials. 1999. *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*. E 917. West Conshohocken, PA: American Society for Testing and Materials.

[53] American Society for Testing and Materials. 2001. *Standard Guide for Evaluating Economic Performance of Alternative Designs, Systems, and Materials in Compliance with Performance Standard Guides for Single-Family Attached and Detached Dwellings*. E 2156. West Conshohocken, PA: American Society for Testing and Materials.

The service life data presented in Chapter 4 assume that the performance of individual building components and systems are independent. In light of the data sources currently available, treating building components and systems as independent is a reasonable assumption. However, as noted in the Introduction, there are instances where poor performance of one component can adversely affect the performance of another. Additional research on the treatment of interdependencies between building components will result in better service life data and should ultimately lead to a systems approach to durability-related issues both at the building component level and the housing unit level. A potential source of information and a platform for conducting additional research on component/system interdependencies is the NFO Survey. The NFO survey already includes a number of questions on the reasons for replacing selected building components. Expanding these questions to include a small set of well-defined interdependencies could result in some significant insights.

Finally, in order to be able to measure progress toward achievement of the PATH vision, periodic reports need to be produced that re-visit the same data sources used to generate the baselines, and refine or expand the original baselines as necessary to meet the changing needs of residential sector stakeholders.

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